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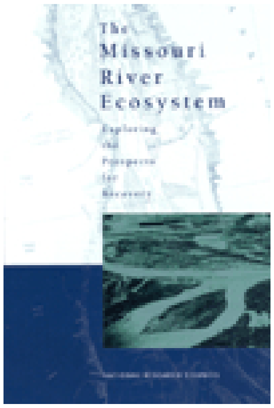

The Missouri River Ecosystem: Exploring the Prospects for Recovery

Committee on Missouri River Ecosystem Science,
National Research Council

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

The Missouri River Ecosystem
Exploring the Prospects for Recovery

Committee on Missouri River Ecosystem Science

Water Science and Technology Board

Division on Earth and Life Studies

National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

Two hundred years ago, Lewis and Clark led their "Corps of Discovery" on an unprecedented expedition to explore the vast dimensions of the nation's longest and largest river basin—the Missouri. Their central charge was to seek a water route to the Pacific Ocean to support commerce and development. Since those early days, the Missouri River and its tributaries have occupied a unique place in United States history. Like many of the nation's major river systems in the nineteenth and early twentieth centuries, the Missouri was viewed as a river to be controlled for purposes of human settlement and as a resource to support economic development. The Missouri River's water development hallmark was the Pick–Sloan Plan, which mandated the construction of a set of vast engineering projects aimed at controlling floods, facilitating navigation and commerce, and inducing agriculture and other forms of economic development in the Missouri Basin.

While many of society's goals were accomplished through the Pick–Sloan Plan, the Pick–Sloan vision was not fully realized. Much of the agricultural and commercial development—including navigation—has not reached anticipated levels of development because of several reasons: shifting economic conditions, a harsh climate in many sections of the basin, and decreasing enthusiasm for large-scale water development projects in the United States. Population growth in the basin has been modest compared to many areas of the U.S. and census data portray a demographic trend of people moving away from the basin's rural areas, with modest population growth in its cities. Just as Lewis and Clark never found an easily-traversed water route to the Pacific Ocean, a clear, consensus vision of the future

Missouri River basin remains elusive. Among the challenges in finding that course is determining the appropriate roles for the symbolic heart of the basin—the Big Muddy.

Our committee extends its gratitude to the study sponsors, the EPA and the Corps of Engineers. Jim Berkley and Ayn Schmitt of EPA (Denver) and Rose Hargrave of the Corps of Engineers (Omaha) are to be commended for their courage and vision in requesting the advice of the National Research Council regarding the condition and the adaptive management of the Missouri River ecosystem. Without their support and encouragement, this study would not have been possible.

In our meetings we sought and received input from many organizations and individuals with deep knowledge of the basin. The committee expresses its appreciation for the information and personal thoughts of many who helped shape its understanding and perception of the Missouri River. Input from local, state, and federal government officials and scientists, representatives of conservation and environmental organizations, trade groups, agriculturists, businesses, Native Americans, and others—too numerous to mention by name—were instrumental in informing our committee's discussions about the Missouri River. Committee members also made numerous, enjoyable personal contacts with people in the basin from many walks of life, which enhanced our knowledge of the relations between people and the environment along the Missouri River. We also reviewed the extensive published literature dealing with the Missouri and large rivers in general. Much of our report contains the reflections of our findings from that literature. The enormity of the system and the diversity of its peoples and issues challenged us. Yet, through vigorous discussion and sharing of ideas, this committee came to a strong consensus about the state of the Missouri River ecosystem and ways in which its rich natural heritage might be restored and preserved, at least in part, for the next two hundred years of American history. I am personally grateful for the privilege of chairing a committee whose members demonstrated not only impressive scientific knowledge, but a sensitivity to the articulation of that science with policy, a sincere interest in our charge, and high degree of civility and camaraderie.

This report also reflects the dedication and diligent work of the NRC staff. The committee, and I as chair, wish to particularly thank Senior Staff Officer Jeffrey Jacobs of the NRC's Water Science and Technology Board. Jeff's clear thinking and guidance to the committee on matters of substance as well as procedure are reflected in the quality of this report. We also thank Anike Johnson for her able handling of logistics for our meetings and the mechanics of integrating material for the report. Jon Sanders provided able editorial support during the final stages of the report's review. In addition to the NRC staff, Rhonda Bitterli provided excellent editorial advice on the committee's draft report.

This report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with the procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Barry Gold, U.S. Geological Survey; Lance Gunderson, Emory University; Lynne Lewis, Bates College; Diane McKnight, University of Colorado; Brian Richter, The Nature Conservancy; John Thorson, attorney and water policy consultant, Oakland, California; and M. Gordon Wolman, Johns Hopkins University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Debra Knopman of RAND. Appointed by the National Research Council, she was responsible for making certain that an independent examination of the report was carefully carried out in accordance with the institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Today, the nation and the institutions and citizens in the Missouri Basin are embarking on another journey of discovery. In some ways, this journey resembles Lewis and Clark's expedition of two hundred years ago, in that stakeholders in the Missouri Basin will be challenged to explore the unknown and seek ways to ensure the most complete understanding and best use for America of one of her great rivers. We wish them luck and hope this report assists them in charting their course.

Steven P. Gloss, Chair

Contents

APPENDIXES

Executive Summary

Over the past century, human activities have caused substantial ecological changes to the Missouri River ecosystem. By any measure, the Missouri River ecosystem—the Missouri River's main channel and its floodplain—has experienced significant reductions in natural habitat and in the abundance of native species and communities. There have also been substantial reductions in the daily and annual variability of hydrologic and geomorphic processes. Causes of these changes include the removal of snags from the river in the late 1800s; introduction of nonnative fish species beginning in the late 1800s; navigation enhancement beginning in the early 1900s; and damming and flow regulation of the mainstem Missouri River beginning in the 1930s. Land use changes (including urbanization, agriculture, transportation infrastructure) and population growth have also affected the ecosystem in less direct but important ways.

River systems have often proved remarkably resilient, withstanding a variety of human modifications and still responding positively to ecosystem restoration efforts. Strategies for improving ecological conditions in large river systems are relatively new, but some smaller rivers have exhibited rapid and positive ecological responses. In the Kissimmee River in Florida, for example, plant communities, fish, and invertebrates responded favorably to water-level manipulation experiments in the early 1980s. More recently, the breaching of Edwards Dam on Maine's Kennebec River in 1999 resulted in increases in the abundance of select bird and fish species. Nonetheless, there is a point beyond which a large, degraded river system can only be recovered with costly remediation efforts. Some losses—such as species extinction—can never be restored.

Given the size and complexity of the Missouri River ecosystem, it is not clear where the point of irreparable environmental change lies, or how close the Missouri River ecosystem might be to passing that point. However, the following changes in the Missouri River ecosystem jeopardize its fundamental natural processes: the loss of natural flood pulses; the loss of natural low flows; straightening of stream meanders and the elimination of cut-and-fill alluviation; losses of natural riparian vegetation; reductions in water temperature variation; introduction of nonnative species; and extensive bank stabilization and stream channelization. Specific examples of twentieth century changes in the Missouri River ecosystem include the following:

- Nearly 3 million acres of natural riverine and floodplain habitat (bluff to bluff along the Missouri River's mainstem) have been altered through land-use changes, inundation, channelization, and levee building.
- Sediment transport, which was the hallmark of the pre-regulation Missouri River (and was thus nicknamed "The Big Muddy"), has been dramatically reduced. Sediment transport and deposition were critical to maintaining the river system's form and dynamics. For example, before the 1950s, the Missouri River carried an average of roughly 142 million tons of sediment per year past Sioux City, Iowa; after closure of the dams, an average of roughly 4 million tons per year moved past the same location.
- Damming and channelization have occurred on most of the Missouri River basin's numerous tributary streams, where at least 75 dams have been constructed.
- The amplitude and the frequency of the Missouri River's natural peak flows have been sharply reduced. With the occasional exception of downstream sections in the state of Missouri, the Missouri River no longer experiences natural spring and summer rises and ecologically-beneficial low flows at other times of the year.
- Cropland expansion and reservoir impoundment have caused reductions in natural vegetation communities. These vegetation communities continue to shrink with the additional clearing of floodplain lands. The remaining remnant areas will be critical in any efforts to repopulate the floodplain ecosystem.
- Reproduction of cottonwoods, historically the most abundant and ecologically important species on the river's extensive floodplain, has largely ceased along the Missouri River, except in downstream reaches that were flooded in the 1990s and in upstream reaches above the large dams.
- Production of benthic invertebrates (e.g., species of caddisfly and mayfly) has been reduced by approximately 70 percent in remnant unchannelized river reaches. Benthic invertebrates are an important food

source for the river's native fishes and an important component of the river's food web.

- Of the 67 native fish species living along the mainstem, 51 are now listed as rare, uncommon, and/or decreasing across all or part of their ranges. One of these fishes (pallid sturgeon) and two avian species (least tern and piping plover) are on the federal Endangered Species List.
- In many reaches of the river, nonnative sport fishes exist in greater abundance than native fish species. The nonnative fishes are often more tolerant of altered conditions of temperature, turbidity, and habitat. Although some nonnative fish produce substantial economic benefits, nonnative species may also contribute to the declining abundance of native fish.

These ecosystem changes are not merely abstract, scientific measurements; they also represent the loss of valued goods and services to society. Examples of ecosystem goods and services include outdoor recreation, biomass fuels, wild game, timber, clean air and water, medicines, species richness, maintenance of soil fertility, and the natural recharge of groundwater. It is often difficult to recognize the economic values that are lost with declines of these ecosystem benefits, largely because they have historically not been carefully measured. But ecosystem-based activities often provide important economic benefits. For example, thousands of people enjoy canoeing on the Missouri River in Montana each year, which provides an important source of tourism-based income.

The values of many of these services historically have not been monetized and are not traded in economic markets. Changes in the benefits flowing from these services are thus not easily recognized. With the exception of select outdoor recreation activities, most ecosystem goods and services tend to be undervalued by decision makers and in resources management policies. But there is a growing recognition that the replacement costs of these services, assuming their replacement is even possible, would be very high.

Degradation of the natural Missouri River ecosystem is clear and is continuing. Large amounts of habitat have been transformed in order to enhance social benefits, and the ecosystem has experienced a substantial reduction in biological productivity as a result. Natural riverine processes, critical to providing ecosystem goods and services, have been greatly altered. The ecosystem has been simplified and its production of goods and services has been greatly compromised.

Degradation of the Missouri River ecosystem will continue unless some portion of the hydrologic and geomorphic processes that sustained the pre-regulation Missouri River and floodplain ecosystem are restored—including flow pulses that emulate the natural hydrograph, and cut-and-fill alluviation associated with river meandering. The ecosystem also faces the prospect of irreversible extinction of species.

STATE OF THE SCIENCE

There is a rich, extensive body of scientific research on the Missouri River ecosystem that can provide the foundation for future river management actions. For example, a 1997 technical report from the U.S. Geological Survey listed 2,232 studies of the Missouri River ecosystem. These scientific studies date back to Lewis and Clark's epic 1804–1806 expedition. Since then, many individuals and government agencies have studied the basin's natural vegetation, fishes, water quality, and impacts of dams. This research has greatly improved scientific understanding of the river's ecosystem and how it has changed. These studies have provided careful documentation of the ecological changes described in this report.

Research on the Missouri River ecosystem provides a sound scientific understanding of ecological structure and the controlling river processes, and how they were impacted by human actions during the twentieth century. Although knowledge of the ecological intricacies within a system as large as the Missouri River ecosystem will always be limited by scientific uncertainties, the system's broad ecological parameters and patterns are currently well understood.

Nonetheless, existing studies are only a starting point for future management choices because this extensive body of research has not been adequately synthesized. Further, the studies have tended to focus on specific species or portions of the river. Only a few studies of Missouri River ecology view the river as a single system from headwater to mouth, or as a single system that considers biological and physical linkages.

The lack of synthesis and utilization of these scientific data may be as much a function of institutional and political barriers as it is of the limitations of the scientific information itself. Neither discrete scientific disciplines nor mission agencies have been provided with sufficient incentives to conduct this synthesis and integration. Without this fundamental information, cast within a system-wide perspective encompassing the entire Missouri River ecosystem, truly comprehensive assessments of the ecological state of the Missouri River are not possible.

The most significant scientific unknowns in the Missouri River ecosystem are how the ecosystem will respond to management actions designed to improve ecological conditions. In addition to improving ecological conditions, such actions can also help supplement existing scientific knowledge, especially in understanding how select ecological variables respond to different environmental conditions. Management actions, cast as carefully circumscribed and monitored experiments, are necessary in order to advance our understanding of how regulated rivers respond to changes. It is important that ecosystem monitoring programs be designed specifically to produce results that serve as input into river ecosystem recovery programs.

The emerging paradigm of adaptive management provides a useful conceptual basis for framing such management actions. The concept has been and is currently being used to guide ecosystem restoration efforts in the Colorado River, the Columbia River, and the Florida Everglades. Adaptive management is also being initiated by Missouri River management agencies. The U.S. Army Corps of Engineers, for example, in its August 2001 revised draft environmental impact statement for the Missouri River Master Water Control Manual, acknowledges the importance of adaptive management.

This committee was requested to comment on "policies and institutional arrangements . . . that could promote an adaptive management approach to Missouri River and floodplain ecosystem management."

Adaptive management recognizes that scientific uncertainties and unforeseen environmental changes are inevitable. It thus seeks to design organizations and policies that can adapt to and benefit from those changes. Adaptive management is not merely an elaborate "trial and error" approach. Rather, it emphasizes the use of carefully designed and monitored experiments, based on input from scientists, managers, and citizens, as opportunities to maintain or restore ecological resilience and to learn more about ecosystems. These actions are monitored for scientific findings to help improve understanding of how policy decisions affect ecosystems. Findings from ecosystem monitoring are then to be used to appropriately adjust management policies. Adaptive management requires that clear goals and desired outcomes be established so that progress toward desired future conditions can be assured.

Although adaptive management is a powerful approach that holds great potential, it should not be viewed as a panacea for Missouri River basin management and ecosystem improvements. The committee was keenly aware that the practice of adaptive management is "a work in progress" and that there is inadequate experience with successful or unsuccessful experiments to comprehensively evaluate the underlying theory. Adaptive management is not necessarily easy to implement and execute and, like the Missouri River basin itself, presents many complexities. In those ecosystems where it has been implemented, it has proven useful in many ways. However, endangered species are still listed, stakeholders still disagree with one another, and key management agencies are constrained by resources, legal mandates, and political realities. Nonetheless, there can be little disagreement that a new management paradigm is needed if further declines in the Missouri River ecosystem are to be halted and reversed. Adaptive management represents a framework for promoting stakeholder discussion and for strengthening the links between the Missouri River ecosystem and the region's economies and societies. Just as adaptive management encourages experiments, implementation of adaptive management will in itself represent an experiment. But no other alternative restoration strategy holds the promise that adaptive management does, and federal, state, and local governments, as well as several other National Research Council committees, have embraced the concept as an important instrument to promote biodiversity conservation and restoration.

The U.S. Army Corps of Engineers, in cooperation with the U.S. Fish and Wildlife Service and several state agencies, has completed and is implementing several habitat preservation and restoration projects along the Missouri River. These projects represent useful steps toward recovering the Missouri River ecosystem. However, they are limited in scope, are insufficiently coordinated among agencies and among various reaches of the river, receive inconsistent funding, and lack adequate support for monitoring. These programs also are not framed within an overarching plan for recovering key elements of the Missouri River's pre-regulation hydrologic and geological processes. The sum of these efforts is insufficient to noticeably recover ecological communities and fundamental physical processes in the Missouri River ecosystem. To substantially improve the ecosystem, a more systematic and better-coordinated approach that considers ecological conditions on par with other management goals in the entire Missouri River system will be required.

MISSOURI RIVER NAVIGATION AND BANK STABILIZATION

No Missouri River management issue has polarized the river's stakeholders as much as the debate over how the provision of flows and channel depths for navigation has affected the Corps' ability and willingness to meet ecosystem needs. Improved navigation was a major feature of the mid-twentieth century vision of the 1944 Pick–Sloan Plan, as navigation's future economic benefits were assumed to be substantial. However, the 1950 projections for commercial waterway traffic were overly optimistic; commercial towboat traffic on the Missouri River peaked in 1977 (below projected levels) and has fallen slowly and steadily since then.

Missouri River navigation, conducted on the river's 735-mile channelized stretch between Sioux City, Iowa and St. Louis, Missouri, is controversial for both economic and environmental reasons. The current dam and reservoir operation schedules reduce the river's natural hydrologic variability in order to provide a steady and reliable 9-foot deep navigation channel. Such operations run counter to established river science, in which a large degree of natural hydrological variability is essential to biological productivity and species richness of large floodplain rivers. A resolution of the differences between managing flows for navigation or for more natural hydrology is constrained by the fact that the benefits of navigation are expressed in dollars, while the benefits of ecosystem improvements from operational changes have yet to be monetized.

The ultimate decision regarding the proper balance between these uses is a public policy issue and, as such, was beyond this committee's charge. Nevertheless, this issue is so crucial to the river's future that this committee could not ignore it. Differences of opinion may be artificially magnified by framing Missouri River navigation as an "all or nothing" issue. Cooperative dialogue might be easier if incremental changes in navigation and river management were considered.

Because net national navigation benefits are relatively small in total, and because waterway traffic volumes decrease moving upstream, an incremental analysis of the economics of retaining segments of the navigable waterway would be useful. Relaxing the responsibility to maintain navigation flows would make it demonstrably easier to introduce flows for improving river ecology in that segment. As an example, if the segment from Sioux City, Iowa downstream to Omaha, Nebraska proved to be uneconomic when comparing its incremental benefits with its incremental costs—factoring in the values of all potential ecosystem goods and services—then that segment would be a candidate for enhancing river ecology through operational changes. Ecological enhancement, however, would not necessarily proceed rapidly. The banks along the river's navigable channel are stabilized and contain communities and other important infrastructure in many areas. If it is decided to enact management actions to improve the state of the ecosystem, and if those management actions are to be effective, some degree of Missouri River meandering must be restored. Allowing the Missouri River to meander would require a significantly wider public corridor in some portions of the channel than currently exists. This would require close coordination with those who live and work along the river. In some cases, significant improvements in river ecology may require relocations.

In proceeding segment by segment, the analysis should discover the point at which it is beneficial to retain navigation to the mouth of the river. The case for retaining some navigation might be stronger if navigation were discontinued or less fully supported in those segments where it is economically inefficient. Congress should give the Corps of Engineers authority to provide navigation services on an incremental basis along the channelized portion of the Missouri River, to be exercised on the basis of analysis and stakeholder input.

POLICIES, INSTITUTIONS, AND ADAPTIVE MANAGEMENT

The Corps of Engineers constructed and operates six of the seven mainstem dams on the Missouri River; the U.S. Bureau of Reclamation operates the seventh, Canyon Ferry Dam, east of Helena, Montana. When the Corps of Engineers constructed five of the Missouri River mainstem dams in the 1950s and 1960s after passage of the Pick–Sloan Plan, goals for dam and reservoir operations were to reduce flood damages, enhance navigation, generate hydroelectric power, and store water for irrigation. But changes in social preferences have resulted in a new mix of uses and stakeholders on the Missouri River today. Many of these new uses revolve around recreational and environmental considerations, such as boating and sport fishing. Some Missouri River stakeholders, such as environmental and recreational groups, call for revised operations and a redistribution of the river's benefits. Other stakeholders, such as the navigation industry, the hydropower industry, and floodplain farmers generally prefer the status quo.

Scientific knowledge, economies, and social preferences have clearly changed across the Missouri River basin since the mainstem dams were planned and constructed. However, the institutional and policymaking framework for Missouri River management has not changed accordingly. The decision-making context for the Missouri and its tributaries is characterized by prolonged disputes, disaffected stakeholders, and degrading ecological conditions. Barriers to resolving this policy gridlock on the Missouri River include a lack of clearly stated, consensus-based, measurable management objectives, powerful stakeholders' expectations of a steady delivery of entitlements, and sharply differing opinions and perspectives among some Missouri River basin states.

Current management protocols for operating the Missouri River system represent an accretion of federal laws, congressional committee language, appropriations instructions, and organizational interpretations that have been enacted or developed over the past century. This guidance has generally not been updated to reflect changing economic and social conditions, new needs in the basin or the nation, or advances in scientific knowledge. The Corps of Engineers and some basin stakeholders view the collective statutes, committee reports, and agency interpretations as barriers to prospective management changes that would seek to balance ecological values and services with current realities and values of navigation, recreation, and sound floodplain management. Although this committee believes the Corps of Engineers may have greater legal authority to manage the Missouri River system than it has exercised, the Corps' ability to do so has been constrained by sharp differences of opinion among stakeholders. If the condition of the Missouri River ecosystem is to improve, agencies responsible for adaptive management must have clear lines of authority and the necessary resources to work toward this goal.

The Corps of Engineers has always set the water release schedules for the Missouri River mainstem dams. Guidance for mainstem dam water release priorities is established in the Corps' Missouri River Main Stem Reservoir System Reservoir Regulation Manual, also known as the "Master Manual." Decisions regarding water release schedules from the Missouri River mainstem reservoirs ultimately determine the distribution of the river's benefits. As mentioned, these decisions have become increasingly controversial and pose challenges to the Corps.

In the late 1980s, the Corps of Engineers began a revision to its 1979 Master Manual that today—thirteen years later—is not yet complete because of competing demands for the river's resources and sometimes strong differences of opinion. In working toward this revision, the Corps has consulted with numerous stakeholders and the public at large across the Missouri basin, including environmental groups, the navigation industry, farmers, and other floodplain residents and communities. Any agency would be challenged to find a solution amenable to all users in the current context of Missouri River management, and a consensus on how the dams and reservoirs are to be operated has remained elusive. A moratorium on further revision of the Master Manual should thus be implemented until such revisions reflect a collaborative, science-based approach based upon adaptive management to improve the condition of the Missouri River ecosystem.

Adaptive management should be adopted as an ecosystem management paradigm and decision-making framework for modifying water resources and reservoir management for the Missouri River ecosystem. As part of this management strategy, the goal of improving ecological conditions should be considered on par with other management goals. Specific Missouri River adaptive management experiments and activities—involving a broad spectrum of river system stakeholders in a collaborative process to establish goals and guidelines for such experiments—should be implemented as soon as possible. Adaptive management actions for improving ecological conditions should be examined and conducted within a systems framework that considers the entire Missouri River ecosystem from headwaters to mouth, as well as the effects of tributary streams on the mainstem.

Determining specific goals and objectives for Missouri River management that society desires will require the participation of a wide spectrum of groups with stakes in Missouri River management. Missouri River mainstem reservoir operations objectives and means, including adaptive management actions, should be set by a formal multiple-stakeholder group that includes, but is not necessarily limited to, the U.S. Army Corps of Engineers, the U.S. Department of Energy, the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, the U.S. National Park Service, Indian tribes, the Missouri River basin states, floodplain farmers, navigation groups, municipalities, and environmental and recreational groups. The stakeholder group should review other adaptive management efforts to learn about successes, failures, and potential management actions that could be usefully implemented on the Missouri. To help resolve scientific uncertainties and to assure progress in considering some level of ecosystem recovery, a scientific peer-review process that includes an independent, interdisciplinary scientific panel should provide solicited input to the stakeholder group.

Support of the U.S. Congress is ultimately needed to help establish acceptable goals for the use and management of the Missouri River system. Congress must also identify the necessary authorities to do so. The stakeholder group should help frame Missouri River management decisions. But if the trends of ecosystem decline are to be halted and reversed, that stakeholder group must define ecosystem improvements as one of its key goals. Federal legislation mandating ecosystem protection and enhancement is one means to help stakeholders focus on Missouri River ecology. Sustained stakeholder participation in a system the size of the Missouri River ecosystem, and in which there are sharp differences of opinion over appropriate management goals, will require sustained commitments of time and resources. Some of the participants may possess inadequate resources and will require assistance to ensure their participation. Successful implementation of adaptive management will also require administrative and facilitation resources.

Congress should provide the necessary legislative authorities and the fiscal resources to implement and sustain an adaptive management approach to Missouri River management. Resources should include administrative and facilitation services for a multiple-stakeholder group to develop consensus positions on river management objectives and reservoir operations policies. To ensure support of the adaptive management program and management actions that balance contemporary social, economic, and environmental needs in the Missouri basin, Congress should enact a federal Missouri River Protection and Recovery Act designed to improve ecological conditions in the Missouri River ecosystem. This act should include a requirement for periodic, independent review of progress toward implementing adaptive management of the Missouri River ecosystem.

1

Introduction

Rivers, watersheds and aquatic ecosystems are the biological engines of the planet.

World Commission on Dams, 2000

The Missouri River basin (Figure 1.1) extends over 530,000 square miles and covers approximately one-sixth of the continental United States. The one-hundredth meridian, the boundary between the arid western states and the more humid states in the eastern United States, crosses the middle of the basin. The Missouri River's source streams are in the Bitterroot Mountains of northwestern Wyoming and southwestern Montana. The Missouri River begins at Three Forks, Montana, where the Gallatin, Jefferson, and Madison rivers merge on a low, alluvial plain. From there, the river flows to the east and southeast to its confluence with the Mississippi River just above St. Louis. Near the end of the nineteenth century, the Missouri River's length was measured at 2,546 miles (MRC, 1895). Large, looping meanders of the main channel, some of which were nearly circular and that measured tens of miles in circumference, were then prominent features of the river. Much of the river has since been dammed, straightened, and channelized, and these large meanders have been virtually eliminated. As a result, the Missouri River's length today is 2,341 miles—a shortening of roughly 200 miles (USACE, 2001).

Between 1804 and 1806, Meriwether Lewis and William Clark led the first recorded upstream expedition from the river's mouth at St. Louis to the Three Forks of the Missouri, and eventually reached the Pacific coast via the Columbia River. The Missouri River subsequently became a corridor for exploration, settlement, and commerce in the nineteenth and early twentieth centuries, as navigation extended upstream from St. Louis to Fort Benton, Montana. Social values and goals in the Missouri River basin in

FIGURE 1.1 The Missouri River Basin.
SOURCE: USACE, undated.

this period reflected national trends and the preferences of basin inhabitants. Statehood, federalism, and regional demands to develop and control the river produced a physical and institutional setting that generated demands from a wide range of interests.

Over time, demands for the benefits from the Missouri's control and management resulted in significant physical and hydrologic modifications to the river. These modifications led to substantial changes in the river and floodplain ecosystem. Numerous reservoirs are scattered across the basin, with seven large dams and reservoirs located on the river's mainstem. Six of these dams were constructed pursuant to a 1944 agreement between the U.S. Army Corps of Engineers and the Department of the Interior's Bureau of Reclamation. The agreement, ratified by the U.S. Congress, is known as the Pick–Sloan Plan and is the effective existing management regime for the Missouri River. The Pick–Sloan Plan represented a merger of Missouri River basin development plans that were formulated independently in the early 1940s by the Corps of Engineers (the Corps' "Pick Plan" was headed by Colonel Lewis A. Pick) and the Bureau of Reclamation (the Bureau's "Sloan Plan" was headed by Regional Director William G. Sloan). The separate plans were coordinated in Senate Document 247 (S.D. 247), which was part of the Flood Control Act passed by Congress on December 22, 1944. The final paragraph of S.D. 247 states that the plan "will secure the maximum benefits for flood control, irrigation, navigation, power, domestic, industrial and sanitary water supply, wildlife, and recreation."

The first public mainstem dam on the Missouri River pre-dated Pick–Sloan. The Fort Peck Dam was built in Montana in the 1930s as a Works Progress Administration project promoted by President Franklin D. Roosevelt. The five mainstem dams downstream of Fort Peck and dozens of tributary dams were constructed as part of Pick–Sloan. Missouri River mainstem reservoirs behind Fort Peck Dam in Montana (Fort Peck Lake), Garrison Dam in North Dakota (Lake Sakakawea), and Oahe Dam in South Dakota (Lake Oahe) are three of the nation's five largest human-made lakes (only Lake Mead and Lake Powell, both on the Colorado River, are larger). Although the river and its tributaries are extensively controlled by dams, channel modifications, and bank stabilization projects, the Missouri River is still subject to flooding, especially on the lower river. Like most major U.S. water projects, the Missouri River dams were authorized and built prior to the passage of modern environmental statutes such as the National Environmental Policy Act (1969) and the Endangered Species Act (1973), but not the Fish and Wildlife Coordination Act of 1934, which pre-dates most of the dams.

The Corps of Engineers constructed and operates six of the Missouri's seven mainstem dams (the Bureau of Reclamation constructed and operates Canyon Ferry dam, the comparatively small mainstem dam farthest upstream). Operations of these six dams are guided by the Corps' 1979 Missouri River Main Stem Reservoir System Reservoir Regulation Manual, usually referred to as the "Master Manual." A severe drought across the basin in the late 1980s and early 1990s focused national attention on the tensions and conflicts among management objectives and competing beneficiaries. During this drought, upper basin reservoirs were drawn down (reducing benefits for recreation and tourism), and lower basin states experienced disruptions to navigation and water supplies.

The pronounced drought of 1988–1992 affected most parts of the Missouri River basin. Negative impacts on reservoir-based recreation (upstream), on navigation (downstream), and on threatened and endangered species were so severe that in 1989, Congress directed the Corps to review the Master Manual. That review was conducted according to guidelines in the National Environmental Policy Act (NEPA), which requires the Corps to conduct an environmental impact statement (EIS) regarding changes in dam operations. As early as August 1994, the U.S. Fish and Wildlife Service (USFWS) issued jeopardy opinions (which state that a proposed action will jeopardize the existence of a threatened or endangered species) regarding operation of the Missouri River dams and the threat to federally listed species (the Fish and Wildlife Service opinions were issued as part of the environmental impact study process). This followed the Corps' issuance of the Master Manual Draft Environmental Impact Statement, which recommended changes in the management of the dams and reservoirs. The Corps conducted public hearings on this draft document. These hearings revealed controversies and passionately-held beliefs surrounding the river's many users. A consensus emerged that recognized the need for improved ecological monitoring and scientific knowledge to improve river management. Nevertheless, the National Environmental Policy Act environmental impact statement process—initiated when the Corps began revisions to its Master Manual in 1989—and a final revision of the Corps' Master Manual for operation of the Missouri River system had not been completed in early 2002, nearly 14 years after the Master Manual revision process began. Congress, the Missouri River basin states, and the basin's water users and interest groups disagree on the appropriate water release schedule (including timing, locations, and quantities of water) for the Missouri River's mainstem reservoirs.

In 1999, with sponsorship of the U.S. Environmental Protection Agency (EPA) and the Corps of Engineers, the Water Science and Technology Board of the National Research Council (NRC) formed a committee of experts to help provide a better scientific basis for river management decisions in the Missouri River basin. This study complements similar NRC studies of the Columbia River basin, the Colorado River basin, the Florida Everglades, and the Upper Mississippi River. It also recognizes a growing public interest in redressing modifications made to large river ecosystems. This committee was given the following charge:

> This committee will provide a general characterization of the historical and current status, and important ecological trends, of the Missouri River and floodplain ecosystem. The committee will provide a review of the available scientific information on the Missouri River and floodplain ecosystem, and will identify and prioritize scientific information needs for improved Missouri River management. The committee will also recommend policies and institutional arrangements that could improve scientific knowledge of the Missouri River and floodplain ecosystem, and those that could promote adaptive management of the Missouri River and floodplain ecosystem.

The committee's task was thus divided into three objectives:

> 1) Characterize the historical and current ecological status of the Missouri River and floodplain ecosystem. This overview will identify key ecological conditions, changes, and processes, endangered and threatened species, trends and relevant time scales, and gaps in and the limits of that knowledge.

> 2) Identify and describe the general state of existing scientific information on the Missouri River and floodplain ecosystem. Identify and prioritize the key scientific questions to be addressed and the key scientific information needed for improved Missouri River management.
>
> 3) Recommend policies and institutional arrangements for improving Missouri River and floodplain ecosystem monitoring and research, and those that could promote an adaptive management approach to Missouri River and floodplain ecosystem management.

This committee began its two-year study late in 1999. Five meetings were held along the river: Bismarck, North Dakota; Columbia, Missouri; Great Falls, Montana; Omaha, Nebraska; and Pierre, South Dakota (a sixth meeting was held at the National Academies' Beckman Center in Irvine, California, in February 2001). The committee spoke with federal and state scientists and engineers, representatives from Indian tribes, experts on Missouri River institutions and policies, groups interested in Missouri River ecology and river management, the commercial navigation industry, and many citizens.

This report focuses on the Missouri River ecosystem. However, an understanding of the larger context of water resources development is helpful in explaining some of the patterns reflected across the Missouri basin. Namely, changing values and water management policies in the United States are part of a larger global shift in which assumptions about the benefits of dams and the ability to appropriately distribute those benefits are being rethought.

ECOLOGICAL CONDITIONS AND TRENDS IN U.S. RIVERS

The rivers of the United States underwent considerable hydrologic and ecological changes during the twentieth century. The most obvious of these changes was the inundation of extensive stretches of these rivers behind dams. The twentieth century saw the Corps of Engineers and the Bureau of Reclamation, along with local, state, and private entities, construct hundreds of dams and greatly increase water storage. For example, in a given year, 60 percent of the United States' entire river flow can be stored behind dams (Hirsch et al., 1990). Dams in the Missouri River basin have the capacity to hold roughly 106 million acre-feet of water, with the six Corps of Engineers Missouri mainstem reservoirs having a combined capacity of roughly 73.4 million acre-feet, making it North America's largest reservoir system (USACE, 2001). The waters stored by these reservoirs are intended to serve multiple purposes, including irrigation, recreation, and controlled releases for navigation enhancement. The reservoirs are also operated so that flood-control storage is available, an amount that fluctuates through the year in response to snowpack and precipitation conditions in the basin.

Major hydrologic changes in some sections of the Missouri River attended the closures of the Corps' mainstem Missouri dams: Fort Peck in 1937, Fort Randall in 1952, Garrison in 1953, Gavins Point in 1955, Oahe Dam in 1958, and Big Bend Dam in 1963. When they were constructed, the Missouri River mainstem dams were intended to help control river flows and to reduce streamflow variability. Today, however, there is a better understanding of and appreciation for the ecological values and services supported by streamflow variability (Box 1.1 describes the values of ecosystem goods and services).

Decreases in riverine wetlands and other riparian (streamside) habitats in U.S. river systems have resulted from population growth and economic development, as well as from structural alterations (e.g., straightening of channels, bank stabilization, and construction of wing dams) designed to constrict flows to a main channel. A variety of indicators might be used to measure changes in these ecosystems. To use one example, a National Research Council committee estimated that total wetland acreage in the contiguous United States decreased by approximately 117 million acres—half the original total—by the mid-1980s (NRC, 1995). Another study found that two-thirds of the pre-European settlement areas of riparian vegetation in the United States have been replaced by other land uses (Moberly and Sheets, 1993). Regardless of the measure chosen, U.S. riparian ecosystems have been greatly altered during the past century.

Human impacts on U.S. rivers have reduced populations of many aquatic species, including some extinctions. In the Columbia River basin, Pacific salmon have disappeared from about 40 percent of their historical breeding ranges over the past century (NRC, 1996). In the Upper Mississippi–Illinois River system, the number of mussel species has declined by 23 percent to 44 percent since European settlement in the nineteenth century (USGS, 1999). Only four of eight endemic fishes remain in the Grand Canyon reach of the Colorado River, and some of these are threatened or endangered (Minckley, 1991).

Engineered changes in the nation's rivers have enhanced competition, predation, and other detrimental interactions between native and nonnative species (Minckley and Deacon, 1991), which has contributed to the demise of native species. Missouri River reservoirs and river segments presently contain populations of exotic fishes, including cisco, several salmon and trout species, and several Asian carp species (Hesse et al., 1989). Some of these species have contributed to the development of economically important recreational fisheries. On the Upper Mississippi River, scientists reported increased abundance of species such as bluegill and largemouth

Box 1.1
Ecosystem Goods and Services

Although knowledge of the importance of ecosystems to societies and economies dates back centuries, discussion of nature's importance in terms of goods and services is a relatively recent phenomenon. Because many functions provided by ecosystems are not monetized and are not traded in markets, values are often under-appreciated by the public and by decision makers (Daily, 1997). For example, clean air and clean water provided by ecosystems are fundamental to healthy societies and economies, but price tags are generally not affixed to air and freshwater systems. They thus may be treated as having no monetary value in market-based decisions. But if rational natural resources decisions are to be made, it is important to understand how ecosystems provide value to societies and the magnitude of those values.

Ecosystem goods and services include fish protein, fish-based recreation, biomass fuels, wild game, timber, clean air and water, medicines, species richness, maintenance of soil fertility, and natural recharge of groundwater. Consistent with the fact that ecosystem goods and services are generally not priced, are not traded in markets, and are not owned, they tend to become needlessly scarce. To remedy this, conservation programs that protect fish and wildlife are enacted, parks and natural reserves are created, the use of the biosphere as a sink for wastes is regulated, and programs aimed at restoring natural habitat are mandated.

A variety of approaches are in use to correct for the unowned and unpriced nature of many ecosystem goods and services. Tradable rights or quotas have been introduced for certain pollutants and in some fisheries. Charges are levied by governments to prevent the overuse of certain goods and services. Several methods are used to place simulated market values on goods and services that would otherwise be unpriced in policy making or in court decisions.

bass, which colonized habitats with slow-moving (lentic) water, after the river's navigation dams were constructed (Fremling and Claflin, 1984).

SHIFTING VALUES AND PUBLIC PREFERENCES

Large, regional water projects no longer enjoy the widespread political support they once did. The economic rationale for these projects has eroded and there is today more concern over these projects' environmental and social costs. As a result, the arid and semiarid western United States is shifting from the reclamation era—characterized by the construction of large, federally subsidized regional water projects—to an era of reallocation, conservation, and ecosystem restoration. The Bureau of Reclamation today focuses on management and maintenance of existing projects and on ecological improvements in degraded stream systems. Similarly, the Corps of Engineers is faced with the challenge of carrying out engineering and construction activities while balancing competing social, environmental, and economic demands in highly developed and highly controlled river systems. The Corps' traditional roles have been expanded by Congress to include environmental restoration and programs that address environmental problems associated with existing projects. For example, the Corps plays a central role in the multi-billion dollar Florida Everglades restoration project.

The value of dams today is questioned by segments of society that value environmental preservation and enjoyment. Some smaller U.S. dams have been breached or removed (e.g., Edwards Dam on the Kennebec River in Maine was breached in 1999), and others are scheduled to be removed (e.g., Elwha Dam in the state of Washington). In addition, the possible removal or decommissioning of some large federal dams (e.g., four dams on the lower Snake River and Hetch Hetchy Dam in Yosemite National Park) has been discussed (ASCE, 1997; Gleick, 2000). During the 1980s and 1990s, Congress passed specific legislation aimed at protecting and/or restoring aquatic ecosystems in the Columbia River basin, the Florida Everglades, the Grand Canyon, and the San Francisco Bay Delta. The need to consider the conditions under which dams and hydroelectric power facilities should be retired has also drawn attention from professional engineering groups (ASCE, 1997).

Changing views toward large dams are reflected in the recent report of the World Commission on Dams (WCD, 2000). In 1997, the World Bank and the International Union for the Conservation of Nature and Natural Resources (The World Conservation Union) assembled a group to discuss the highly controversial issues associated with dams. These parties agreed to a proposal to work together to establish a World Commission on Dams (WCD), which in 1998 began a comprehensive global and independent review of the performance and impacts of large dams. The commission's final report was issued in 2000 (WCD, 2000). Although care must be taken in applying findings from the commission's global review of dams to the Missouri River, many of the commission's findings regarding environment, indigenous people, equity, and sustainability are applicable to the Missouri River basin and to the United States. This committee reviewed the commission's report with interest and, where its findings are relevant, refers to this report.

ADAPTIVE MANAGEMENT

To properly balance social, economic, and environmental considerations in large river ecosystems, organizations and management policies must be able to respond to and take advantage of changing environmental, social, and economic conditions, as well as address extreme events. The concept of adaptive management promotes the notion that management policies should be flexible and should incorporate new information as it becomes available. New management actions should build upon the results of previous experiments in an iterative process. It stresses the continuous use of scientific information and monitoring to help organizations and policies change appropriately to achieve specific environmental and social objectives.

Adaptive management promotes collaborative and consensus-based decision-making. Adaptive management promotes "thinking outside the box" and stakeholder discussions about the desired state of the ecosystem. Responsive organizations and policies that can adjust decisions on dam operations are needed to meet changing scientific and social goals: "Dams and the context in which they operate are not seen as static over time. . . . Management and operation practices must adapt continuously to changing circumstances over the project's life and must address outstanding social issues" (WCD, 2000).

Adaptive management requires an organizational and political framework for its full and proper implementation. To be successful, it should be implemented by organizations with sufficient legal authority and political legitimacy to appropriately adjust management policies. Scientific investigations will never eliminate all economic, engineering, environmental, and social uncertainties in large ecosystems like the Missouri River basin. Policy decisions must account for these uncertainties. Organizations responsible for promoting adaptive management must have the legal authority and the stakeholder support necessary to make and enforce recommended changes in current management regimes.

Adaptive management also promotes the advancement of scientific knowledge through carefully designed experiments and monitoring systems. Water resources managers and scientists across the United States are conducting numerous experiments, at a range of spatial and temporal scales, with water releases and diversions to benefit select species and ecosystems. Perhaps the most prominent experiments in river and dam management are controlled releases of high flows from reservoirs. The most famous controlled release in United States water management was a controlled flood from Glen Canyon Dam in March 1996. The controlled flood in the Grand Canyon aimed to restore beaches that had been damaged by decades of low hydrologic variability. The notion of operating a dam to purposely create a large flood represented a milestone in U.S. water management. Former Secretary of the Interior Bruce Babbitt described the event and the process leading up to it: "There was simply no precedent on the Colorado River—or as far as we know anywhere in the history of civilization—for what Interior was proposing to do" (Babbitt, 1999). Beyond reservoir releases, possible adaptive management actions for the Missouri River include changing the length of navigation seasons, changing patterns of irrigation water withdrawals, changing elevations of navigation pools, and constructing notches in flood-control levees.

This committee studied carefully the history of efforts to create coordinated management schemes for the Missouri River basin through federal river authorities modeled on the Tennessee Valley Authority (TVA), through interstate compacts, and through an entity composed of federal, state, and tribal representatives. In general, the proposed organizations lacked the necessary political support to achieve agreement on implementation and have thereby been unable to resolve most intra-basin conflicts. The lack of such a management authority in the Missouri River basin has created a management vacuum that has been filled by the Corps and increasingly by the courts (Thorson, 1994). If adaptive management is chosen as a paradigm by which to coordinate Missouri River management organizations and policies, it must be considered and implemented in the context of these current and historical organizational efforts. It would require Congress, federal and state agencies, Indian tribes, and other public and private stakeholders to forge an agreement placing adaptive management at the center of a process for reaching compromises on the full array of river management issues.

This committee addressed its charge against a backdrop of over a century of actions devoted to developing and managing the Missouri River for economic and social ends. Before evaluating contemporary Missouri River management issues, a review of the historical development of the Missouri River and its floodplain is appropriate.

2

Missouri River History, Management, and Legal Setting

Much of western history is a series of lessons in consequences.

Wallace Stegner, 1962

The Missouri River flows through several different landscapes and physical regions on its path from the Rocky Mountains to the Mississippi River. The mountainous terrain in the basin's western reaches, the aridity in the basin's western and middle sections, and the more humid climate in the eastern part of the basin help explain the basin's ecology, human uses of the land, and its history. Humans have altered the Missouri River and surrounding lands to address both the challenges of limited water supplies during drought and high flows during floods. In some cases, these alterations have led to conflicts among the Missouri basin's upstream and downstream states. They have also resulted in significant modifications of the basin's natural environment in general and of the Missouri River and floodplain ecosystem in particular.

PHYSICAL GEOGRAPHY

During the last Ice Age, glaciers that extended southward from Canada into the northern United States defined the Missouri River basin's northeastern boundary. Glacial lobes directed the Missouri River drainage toward the Mississippi River. Before the glaciers, much of the upper basin (northward of the Bad River's present confluence with the Missouri at Pierre, South Dakota) drained northeastward into Hudson Bay. On the basin's southern margins, a low ridge and the Ouachita Mountains today separate the Missouri River basin from the Arkansas River basin.

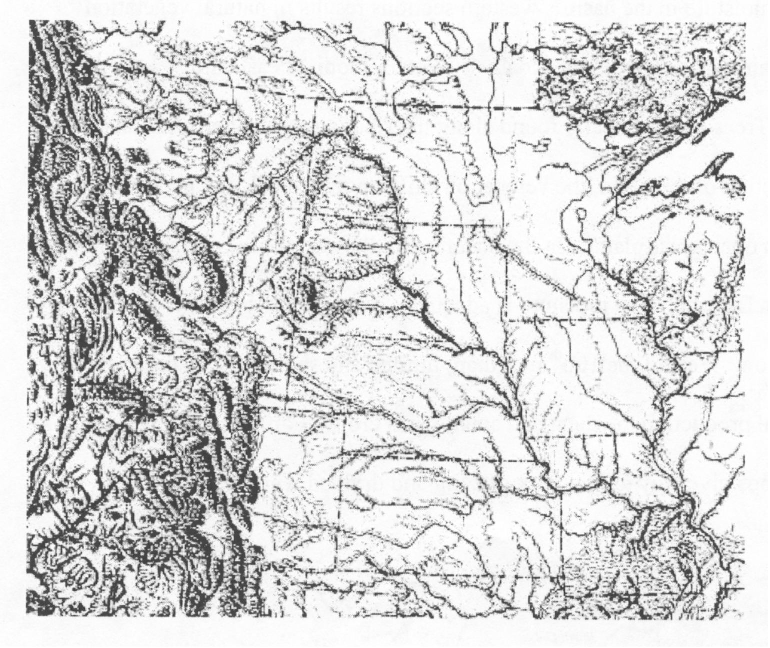

FIGURE 2.1 Missouri River basin landforms.
SOURCE: Erwin Raisz, 1954.

The basin's northern landscapes include level to gently rolling plains and hills composed largely of glacial till. The region between the Missouri River (on the north) and the South Dakota-Nebraska border (on the south) is arid and has eroded to form deep valleys. From there to the basin's southern boundary lie the Great Plains, with their characteristic widely-spaced streams and broad, flat valleys. In the basin's eastern third, the plains give way to upland plateaus and gently rolling till plains. Annual rainfall varies from 8 inches in the foothills of the Rockies to over 40 inches in parts of Missouri and Iowa. Much of the basin is characterized by the cold winters and hot summers associated with a continental climate (drier in the basin's western portions, more humid in the east). Throughout the basin, most rain falls during the spring and summer. The basin's western rivers, such as the Marias and the Yellowstone, gain a large portion of their flow from spring snowmelt.

In eastern portions of the Missouri basin, the climate is humid continental and the vegetation is medium-height bluestem grasses, with mixed oak and hickory forest. Moving westward into more arid regions, grasses generally become shorter and more sparse. In this portion of the basin that straddles the one-hundredth meridian, irrigation is practiced in some areas (some with water tapped from the Ogallala Aquifer), but some crops can be grown without supplemental water during wetter years. Moving westward, low grasslands stretch from near the one-hundredth meridian to the Rocky Mountain foothills, dominating the landscape in the basin's western sections. In this arid section, agriculture consists primarily of ranching, dryland wheat farming, and irrigated agriculture.

Along its course from Three Forks, Montana to its confluence with the Mississippi River in St. Charles County, Missouri, just north of St. Louis, the Missouri River flows through or borders seven states, with the river basin encompassing ten states. The westernmost tributaries of the Missouri River begin at elevations near 11,000 feet above sea level. Flowing downstream and eastward through Montana, the Missouri River is joined on the north by the Milk River, the Missouri's only major tributary that originates in Canada. Farther downstream, the Yellowstone River joins the Missouri near the Montana–North Dakota border. It is then joined by the Little Missouri, Knife, Cheyenne, Bad, Grand, Niobrara, Platte, and Kansas rivers and several smaller tributaries, all of which enter from the Missouri's right bank. Between the Milk River in Montana and the James River (which enters the Missouri just northwest of Sioux City, Iowa, on the southern South Dakota boundary), no major tributaries join the Missouri from the north (its left bank). Downstream from the Missouri River–James River confluence, the Vermillion, Big Sioux, Little Sioux, Chariton, Osage, and Gasconade rivers enter the Missouri from both the left and right banks. Where the Missouri joins the Mississippi just above St. Louis, the Missouri River has fallen to an elevation of slightly less than 400 feet above sea level.

HUMAN SETTLEMENT

Native Americans were the Missouri River basin's first known inhabitants. Spanish explorers, followed by British and French fur traders, were the first Europeans to enter the Missouri basin. The exploration and settlement of the Missouri basin represents a fascinating and well-documented chapter in the history of United States' westward expansion (DeVoto, 1947; Webb, 1931).

The basin became part of the United States with the Louisiana Purchase in 1803. President Thomas Jefferson's interests in the basin's physical geography, ecology, and its Native American tribes led to Lewis and Clark's celebrated expedition. Between 1804 and 1806, Lewis and Clark's "Corps of Discovery" explored the river from its mouth to its headwaters and opened the Missouri basin to the exploration and settlement of a growing United States (Ambrose, 1996). In "the greatest wilderness trip ever recorded" (Botkin, 1995), the group's journey was remarkable not only for the distance covered and the dangers and hardships encountered and overcome, but also for its scientific discoveries.

Lewis and Clark's reports led subsequent explorers to see the region as a route to the West for trade with the Indians, and a region for possible mineral extraction. In the early nineteenth century, travelers within the basin relied on the river for transportation and on the benevolence of the natives for their survival. Navigation eventually reached Fort Benton, Montana, in the Rocky Mountain foothills, and carried a great deal of river traffic in the first half of the nineteenth century. But as the railroads expanded and reached the banks of the Missouri (St. Joseph, Missouri, 1859; Bismarck, North Dakota, 1872) and eventually crossed over it to move to the West (reaching Casper, Wyoming, in 1884), reliance on waterways began to decline. Railroads ultimately had a greater influence on the basin's settlement patterns, especially in its upper reaches, than did steamboats and river navigation.

The westward movement brought settlement and farming, as well as commercial hunting. The basin's settlement initially resulted in only limited ecological impacts. But as these activities intensified, they began to change the lives of Native Americans and the ecology of the Great Plains. The Missouri basin's settlement was encouraged by public land policies such as the Homestead Act of 1862 and Desert Lands Act of 1877. However, settlement in the basin's upper, interior reaches was more ephemeral compared to other parts of the west, as droughts and harsh winters there caused many to leave the basin.

During the nineteenth century, the prevailing assumption was that land disposition policies would be sufficient to settle and sustain the West, including much of the Missouri River basin. But by the twentieth century, based in part on John Wesley Powell's surveys of the arid regions of the western United States (Powell, 1878), the federal government realized that more substantial government intervention would be necessary to encourage and sustain further settlement and economic development in the vast, harsh portions of the basin.

CHANGES IN THE MISSOURI RIVER AND FLOODPLAIN

Irrigated Agriculture

Throughout the latter half of the nineteenth century, settlement of the western United States placed increasingly larger demands on the region's limited water resources. This period saw an increase in private sector efforts to move water from rivers to nearby arable lands. For example, by 1850 the Mormons were irrigating over 16,000 acres in the area that would become the state of Utah (Worster, 1985). Within the Missouri basin, irrigation cooperatives appeared in Colorado as early as 1859 (Dunbar, 1983). Small diversion dams were constructed and ditches were dug to carry diverted waters to fields for irrigation. Larger dams were eventually used to create storage reservoirs to capture spring runoff for use in the hot and dry western summers. By the end of the nineteenth century, many basin farmers were collaborating to develop irrigation projects that they hoped would ensure the availability of water for increasing acreage in agriculture.

Settlement of the Missouri River basin's arid areas required states to adjust their water laws to unfamiliar climatic conditions. The doctrine of prior appropriation, which provides that the water rights of users who first put water to beneficial use are senior to water rights established later, or "first in time, first in right," was adopted in varying degrees in the Missouri River basin's arid regions. Scholars continue to debate whether prior appropriation originated in New England to allocate the rights to the flow of streams among mill owners, or whether it was an application of mining and irrigation customs developed in the west (Pisani, 1996). Whatever its origins, it seems clear that prior appropriation represented a conscious effort to develop an irrigation society in an area of variable rainfall.

The two most arid Upper Basin states, Montana and Wyoming, rejected the common law of riparian rights in favor of prior appropriation. States split by the one-hundredth meridian took a more circuitous route to prior appropriation. The Dakotas initially adopted the common law of riparian rights and subsequently followed dual appropriative-riparian systems until the 1950s and 1960s when riparian rights were extinguished. Kansas and Nebraska went through a similar transition (Wells Hutchins, 2 Water Rights in the Nineteen Western States 1-14, 1974). The more humid states of Iowa, Minnesota and Missouri followed the common law of riparian rights and later supplemented them with permit systems.

Areas along the Missouri River have never benefited from irrigated agriculture to the extent that other areas in the west have. Irrigated agriculture was in its infancy in the western United States during the 1850s and 1860s, a period during which farmers had limited political influence. But drought in the late 1880s, combined with the efforts of irrigation advocates such as George Maxwell and William Smythe, created the political momentum for a federal reclamation policy to settle the west (Pisani, 1992).

The Reclamation Act of 1902 established federal support of irrigation in the western United States as a national policy and created the Reclamation Service, later renamed the Bureau of Reclamation. Missouri River basin residents were quick to recognize the potential for securing resources water resources development; they were, however, less able to profit from the program than areas farther west that had established irrigation districts. As western historian Walter Prescott Webb observed, "The United States government, after the most extensive surveys has not selected a project on the High Plains. . . . by law the national government was compelled to put at least one project in each arid state except Texas, but it will be noticed that the projects in Colorado, Nebraska, and North and South Dakota are placed in the most western portions of those states" (Webb, 1931).

By 1904, irrigation projects were under way in the Missouri River basin at several locations. For example, by 1909, the Yellowstone River was being diverted in two locations. By the 1930s, most of the Missouri's tributaries had one or more dams, diversion structures, or pump stations to store water or to shift it from the rivers and streams to arable lands. By 1939, federal dams had been constructed on the Belle Fourche, Milk, North Platte, Platte, Sun, and Shoshone rivers and their tributaries. Construction also was under way on a 14-dam project that would move 260,000 acre-feet of water a year from the Colorado River basin to the Big Thompson River of the Missouri River basin (Tyler, 1992). One pumped irrigation project was built along the Missouri River near its junction with the Yellowstone River. In these projects, irrigated crops such as sugar beets, beans, flax, and grains replaced dryland agricultural crops.

Navigation

As early as 1824, Congress appropriated funds to the U.S. Army Corps of Engineers to remove large tree snags and other obstacles in the Missouri River channel. Government snag boats and river-based work crews continued their efforts to improve navigability through the late 1870s. However, the volume of upper Missouri River traffic began to decline in mid-century, and by the late 1880s, river traffic essentially ended north of Sioux City, Iowa. At about the same time, the Corps began stabilizing riverbanks in populated areas to reduce losses to riverfront property.

In 1910, Congress, under pressure from farming and barge interests, authorized the development of a six-foot-deep navigation channel on the Missouri River from Kansas City to St. Louis. The project stalled, however, when Congress, faced with World War I, did not appropriate adequate funds for the project. By 1915, all activities had essentially stopped. In 1927, the project was resumed when Congress authorized extension of the six-foot-deep channel to Sioux City, Iowa, and authorized a feasibility study of a nine-foot-deep channel from Kansas City to St. Louis. With funding secured, the Corps launched a program combining bank stabilization with dike construction and strategic dredging designed to narrow the river and eliminate meandering. The dike fields soon filled with sediment, restricting the river to a relatively narrow channel. Wide bends were eliminated, the channel was narrowed, and the river's velocity increased. The result was a self-scouring channel that reduced the amount of dredging required. The Corps' focus on the lower basin ultimately linked navigation-enhancement activities and dams for the first time. In 1945, Congress extended the authorization for a nine-foot-deep navigation channel on the Missouri River from Kansas City, Missouri, to Sioux City, Iowa.

Flood Damage Reduction

Despite the hazards associated with the Missouri River's floodplains, the benefits of settling on them attracted settlers and resulted in increased occupancy and development. In the late eighteenth and early nineteenth centuries, there was no coordinated federal program for flood damage reduction structures and policies, and large floods resulted in significant losses of life and property. Congress considered flood control primarily a local responsibility until passage of the 1917 Flood Control Act, which placed flood control on equal footing with navigation within the Corps and authorized Corps flood-control programs on the Mississippi and Sacramento rivers.

In 1927, Congress passed a River and Harbor Act that authorized the Corps to conduct surveys to formulate comprehensive water development plans in several river basins (because the provisions of the surveys were described in House Document No. 308, the surveys were known as the '308 Reports'). In examining the Missouri River basin's flood-control and navigation needs, the Corps identified several major projects intended to assist in flood damage reduction and the development of the basin. There was also catastrophic flooding on the Mississippi River in 1927, which catalyzed further federal involvement in flood-control activities (Barry, 1998). The Flood Control Act of 1936 declared floods a federal responsibility and established a national flood-control policy. Following a major Missouri River flood in 1943, the Corps prepared a report to Congress proposing five major dams on the mainstem Missouri River, two on the Yellowstone River, and five on the Republican River. These flood damage reduction works would be supplemented by levees on the banks of the Missouri River from Sioux City, Iowa, to St. Louis and would complement another ten dams already authorized for construction on Missouri River tributaries (Ferrell, 1993).

Hydropower

Construction of hydropower dams began in the Missouri basin during the second half of the nineteenth century. In 1890, the Corps of Engineers was given responsibility for approving all nonfederal dams on navigable waters. The 1920 Federal Power Act shifted primary responsibility for the approval of such nonfederal dams to the Federal Power Commission after

Congress rejected federal coordinated development in favor of regulated private development (Holmes, 1972). Hydropower was considered a project purpose for most Bureau of Reclamation dams, and the revenue from hydropower sales was often used to help offset funding shortfalls in irrigation repayments. The Corps was also authorized to include hydropower as a project purpose, but only as a subsidiary to flood control or navigation. Taking advantage of the hydropower potential in the upper Missouri basin, private utilities had constructed several hydropower dams on the tributaries upstream from Fort Peck.

THE PICK–SLOAN PLAN

Setting and Impetus

The most important and lasting alteration of the Missouri River ecosystem resulted from the Pick–Sloan Plan. Pick–Sloan was the product both of the Great Depression and the progressive conservation movement's belief that multiple-purpose water projects would stimulate growth in the arid West (Hays, 1999). The gospel of the progressive movement was that growth would follow the "harnessing" of rivers. The Pick–Sloan Plan also reflected the arid lands reclamation movement, which was promoted at the turn of the century by irrigation enthusiasts like George Maxwell and William Smythe.

Unsustainable agricultural practices on the Great Plains, an economic depression, and the prolonged drought in the 1930s that created the Dust Bowl focused the Bureau of Reclamation's attention on additional storage and diversions in the Missouri basin. Bureau of Reclamation engineers subsequently developed plans for three large dams on the mainstem of the Missouri River downstream from Fort Peck, Montana, as well as for dams on the Yellowstone, Niobrara, Platte, Kansas, and Upper Missouri rivers and on several of the Missouri's western tributaries. These proposed projects would irrigate more than 4 million acres in the basin, and an additional 1.4 million acres in the Souris–Red River basin (which lies northeast of the Missouri River basin) through inter-basin water transfers from the Missouri River basin. Proponents of these schemes believed that the projects would not only increase the extent of basin agriculture, but that they would also provide construction jobs for thousands of basin residents (Ferrell, 1993).

As the drought of the 1930s began, it was apparent that even with the future construction of those dams, there would be insufficient water in the Missouri River to maintain a six-foot deep navigation channel. A 1932 Corps report proposed that it build a major dam on the Missouri River at Fort Peck, Montana. The dam was intended to store water that could be released to supplement flows in the Missouri River downstream from Sioux City, Iowa (Ferrell, 1996).

In 1933, Congress passed the National Industrial Recovery Act (NIRA), which authorized the President to undertake public works projects. The Fort Peck project appeared to offer an opportunity to put people in the Upper Missouri basin to work and to support Missouri River navigation. Less than four months after the NIRA was enacted, President Franklin D. Roosevelt directed construction to begin on Fort Peck Dam. By 1939, the dam, then the largest in the basin, was completed and was beginning to store a planned 19.5 million acre-feet of Missouri River water. The dam was approved to provide flow for the authorized Missouri River navigation project and, when feasible, for the development of hydropower under the auspices of the Bureau of Reclamation.

Merging the Plans of the Bureau and the Corps

The Pick–Sloan Plan was an amalgam of separate Missouri River development plans prepared by the Bureau of Reclamation and the U.S. Army Corps of Engineers. The Corps of Engineers was proceeding with plans for flood-control and navigation-enhancement dams and reservoirs under the aegis of its Missouri River Division Engineer, Colonel Lewis Pick. The Corps' plans responded to the devastating 1943 Missouri River floods and to lower basin navigation interests. The Bureau's water development planning for the Missouri River basin was the responsibility of its regional director William Glenn Sloan. The Bureau's chief goals were irrigation development and hydroelectric power generation. It proposed some ninety dams and reservoirs across the basin, along with several hundred irrigation projects covering 4.7 million acres, which would have doubled the basin's irrigated acreage (Carrels, 1999).

Both plans included several large mainstem reservoirs (Figure 2.2 shows the Pick Plan and the Sloan Plan). Both were presented to Congress at the same time that Congress was considering legislation to create a Missouri River Authority that would promote and coordinate comprehensive development. There was thus considerable pressure from President Roosevelt, basin water interests, and influential members of Congress to create a single basin development plan. (Support for Pick–Sloan was not unanimous, however. Native Americans were particularly opposed to it. See Box 2-1.) The similarities between the Pick Plan and the Sloan Plan enabled the two agencies to meet in Omaha, Nebraska in October, 1944 to quickly reconcile the differences between the two plans and combine them into a unified plan. Congress settled the jurisdiction of the two agencies: the Corps would build and operate the mainstem dams and the Bureau would allocate the water dedicated to irrigation. With this and other minor adjustments,

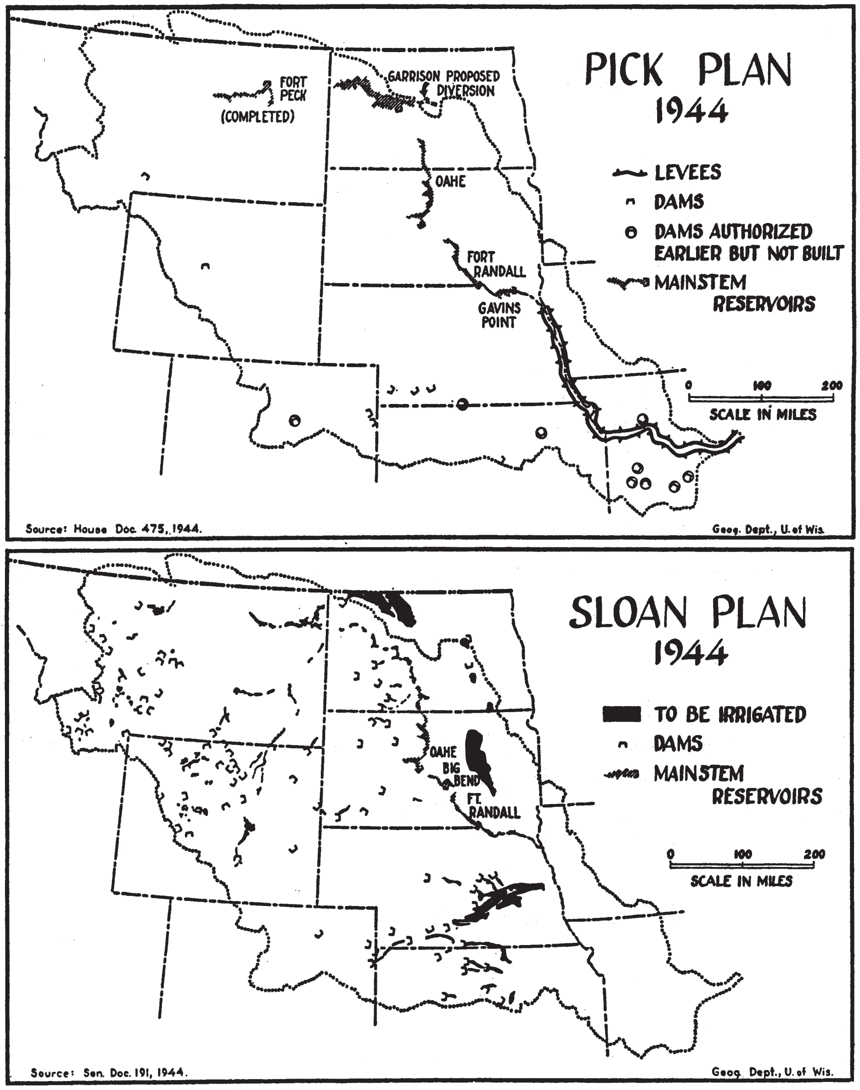

FIGURE 2.2 Proposed water projects under the Pick and Sloan Plans.
SOURCE: Hart (1957).

Box 2.1
Native Americans and Pick–Sloan

The Pick–Sloan Plan was widely supported by water interests throughout the Missouri River basin. Native American tribes, however, took a dim view of the project. The Missouri River floodplains were essential to the tribes. Although the Fort Laramie Treaty of 1851 had granted tribes a permanent homeland for their agricultural economy and culture along the Missouri River, little consideration was given to the tribes in the enactment of the 1944 legislation.

The Pick–Sloan reservoirs displaced thousands of Native Americans from their lands. The five Corps of Engineers mainstem dams displaced roughly 900 Native American families (Lawson, 1982). Tribal groups affected were the Arikaras, Chippewas, Mandans, and Hidatas of North Dakota; the Shoshones and Arapahos of Wyoming; and the Crows, Crees, Blackfeet, and Assiniboines of Montana (Lawson, 1994). In total, the Missouri River mainstem dams flooded over one million acres, much of it belonging to Native Americans (Shanks, 1974). According to Lawson (1994), “The Pick–Sloan Plan . . . caused more damage to Indian land than any other public works project in America.”

All the mainstem dams in North and South Dakota, except Gavins Point Dam, flooded the Native Americans’ most productive land and resulted in large numbers of ousted people. Garrison Dam submerged 155,000 acres on the Fort Berthold Indian Reservation. The reservation ended up with five isolated areas of remnant upland plains. A total of 1,700 people were relocated, which represented 289 of the tribe’s 357 families. The tribe lost its winter grazing in the river bottom and 90 percent of its timber. Most of its lignite coal seams that provided heating fuel became inaccessible. Wild game, an important food source, was greatly diminished. Oahe Reservoir submerged the river bottoms of the Standing Rock and Cheyenne River reservations. 160,000 acres were covered and 351 families were relocated. Up to 90 percent of the timberland and 75 percent of the corn land were submerged. As at Garrison Dam, the tribes lost their winter grazing and their wild game food sources. Big Bend and Fort Randall dams dislocated families from the Yankton, Rosebud, Crow Creek, and Lower Brule Reservations. The dams flooded over 20,000 acres of tribal land, with 17,000 of those being inundated on the Crow Creek and Lower Brule reservations, where 120 families were relocated.

The issue of compensation for the loss of their valued floodplains has not been resolved to the tribes’ satisfaction: “The tribes are still waiting for fair compensation for the lands taken, as well as water and electricity for homes on the reservation” (Thorson, 1994). Between 1947 to 1949, the tribes received $12.6 million for their lost lands (about $81 per acre) and various relocation costs. This level of compensation was viewed as inadequate and was partially rectified over forty later when, in 1991, Congress adopted the recommendations of the Garrison Diversion Unit Joint Tribal Advisory Committee and established a $149 million recovery fund (Thorson, 1994).

Native Americans continue to be involved in the details of Pick–Sloan and Missouri River mainstem dam operations. For example, in October 2000 the Standing Rock Sioux Tribe sued the Corps. The suit related to concerns about the impacts of the fluctuating levels of Lake Oahe on burial sites along the shoreline. The Corps and the tribe subsequently agreed on a settlement that will provide the tribe with an opportunity to help the Corps monitor and stabilize the sites and prevent further erosion (Jehl, 2000).

Congress ratified the Omaha agreement in the Flood Control Act of 1944, but as a Corps historian noted, "[t]he accord did not purport to deal with the policy issues that arose as project development proceeded. . . . The conferees had not considered interdependence of hydropower, irrigation, navigation, and municipal and industrial water supply; nor [sic] the effects on water and related land and fish and wildlife" (Ferrell, 1993).

The Flood Control Act of 1944 also granted the Corps responsibility for flood-control structures in the lower Missouri River and its tributaries in Kansas and Missouri. The Bureau of Reclamation was to construct and operate dams on the Missouri upstream from Fort Peck Dam and on upper basin tributaries. The Corps was to determine flood-control and navigation storage capacities in all dams in the basin, and the Bureau would determine irrigation potential. Subsequently, the Fort Peck project would be operated primarily for irrigation (Ferrell, 1993). The last of Pick–Sloan's five mainstem dams (Table 2.1 and Figure 2.3) was completed in 1963 (Fort Peck Dam was completed before Pick–Sloan). In addition to the Pick–Sloan dams, the U.S. Natural Resources Conservation Service (formerly the Soil Conservation Service) has constructed hundreds of smaller water projects on the Missouri River's tributaries.

State and Federal Governance Under Pick–Sloan

When the Pick–Sloan Plan was signed, it was assumed that its authorization would be followed by a new basinwide governance organization. A Missouri Valley Authority was proposed in 1936 and again in 1944, but these proposals were strongly opposed and were never enacted (Ferrell, 1996; Ridgeway, 1955). A Missouri Basin Inter-Agency Committee (MBIAC) was formed in 1945. The MBIAC's membership included representatives from several federal agencies (Trelease (1953) listed forty-three federal agencies with some role in Missouri basin development) and five governors chosen by a Missouri River States Committee (Thorson, 1994). The MBIAC was hampered by the lack of a clear legal mandate and it was terminated in the early 1970s (ibid.).

Pursuant to Title II of the 1965 Water Resources Planning Act, the Missouri River Basin Commission (MRBC) was established in 1972 and assumed the responsibilities of the former Missouri Basin Inter-Agency Committee. Membership of the MRBC remained a mix of federal and state representatives, but it was organized with a staff and conducted planning studies at the sub-basin level, often focused on basins within a single state. The 1965 federal legislation sought comprehensive water resources planning that went beyond agency-specific efforts and that included substantial roles for basin states. Other basins in which commissions were established were in New England, the Ohio River basin, the Pacific Northwest, the

TABLE 2.1 Corps of Engineers Missouri River Dams

Dam	Year of Dam Closure
Fort Peck	1937
Fort Randall	1952
Garrison	1953
Gavins Point	1955
Oahe	1958
Big Bend	1963

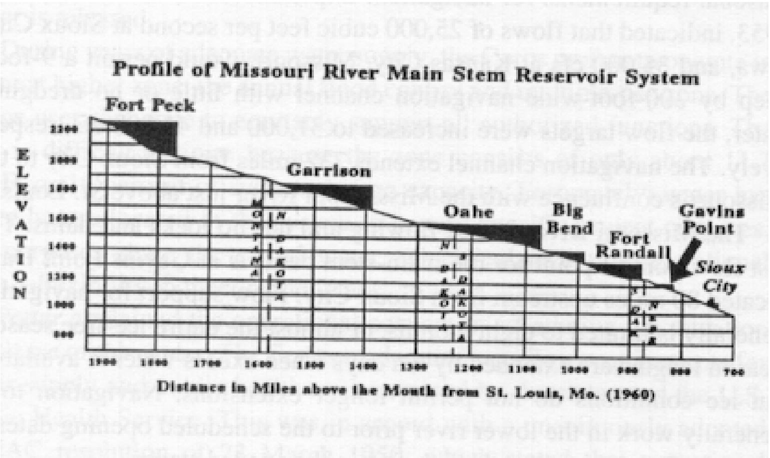

FIGURE 2.3 Missouri River mainstem dam elevations and profile.
SOURCE: USACE, 1979.

Great Lakes, and the Souris-Red-Rainy area (Rieke and Kinney, 1997). However, the commissions were organized at the end of the dam building era and never developed clear missions.

MRBC members represented thirteen federal agencies, all ten basin states, the Yellowstone Compact Commission, and the Big Blue River Compact Administration (Thorson, 1994). The commission developed a management plan, published numerous reports, and established a hydrology model that supported water use monitoring and accounting within the basin. But the "commission's greatest accomplishment was providing a forum for communication and information sharing"(ibid.). This accomplishment did not lead to a basin-wide management regime, however, because the MRBC and the other Title II commissions were generally seen as ineffective, as they had lost their primary mission—the review and coordination of large projects for consistency with other basin resources management objectives. They were thus all terminated in 1981. Termination of the MRBC eliminated one of the important forums for frequent discussions and cooperative activities on Missouri River water management issues.

The Missouri Basin states immediately formed the Missouri Basin States Association (MBSA). As the staff addressed several ongoing studies, issues concerning the rights of states to market water outside the basin arose among the states, and the utility of the MBSA came into question. In 1986, the states attempted to develop a compact agreement, which failed because the states were unable to address all the concerns of the states, and they were unable to develop a common approach to address federal and tribal claims to water (Thorson, 1994). In 1988 the MBSA was dissolved when the basin states either concluded that it was not effective in resolving basin conflicts or was peripheral to their interests (ibid.). In 1990 the MBSA was reconstituted to fill the representation vacuum created by the dissolution, and its membership was expanded to include tribal representation. The MBSA also sought to increase its general base of support throughout the region and was renamed the Missouri River Basin Association (MRBA). Eight basin states are currently members of the association (Colorado and Minnesota currently do not participate). Members are appointed by their governors and normally are senior water management officials. In 1990, the Mni Sose Tribal Water Rights Coalition, which was formed in 1988 to assist 28 of the 29 basin tribes in securing their water interests, became a voting member of MRBA. In 1998, the MRBA attempted to mediate an agreement among the states concerning the development of new operating rules for the Missouri mainstem, but it was unable to achieve consensus.

Another organization that promotes dialogue on Missouri River management issues is the Missouri River Natural Resources Committee (MRNRC). Formed in 1987 to help promote ecological stewardship, membership of the MRNRC includes the state fish and wildlife agencies of the seven states that the Missouri River flows through or borders. The Corps, the U.S. Fish and Wildlife Service, and the U.S. Department of Energy's Western Area Power Administration (WAPA) are ex officio, non-voting members, and the U.S. Geological Survey, the Bureau of Reclamation, and the National Park Service are cooperating members.

Federal agencies with Missouri River management and science responsibilities currently meet once or twice a year on Missouri River issues under the auspices of a Missouri River Roundtable (Box 2.2 lists federal agencies with water science and management roles in the basin). Roundtable meetings focus on identifying prospective collaborative efforts, and they provide members the opportunity to share information on relevant activities.

Roundtable members have mutually agreed to avoid areas of conflict and focus on areas of cooperation.

The net result of the inability of the states and federal government to develop an effective basinwide governance structure is that the Missouri River is currently managed almost exclusively by the Corps of Engineers according to the Flood Control Act of 1944 (which includes the Pick–Sloan Plan).

Pick-Sloan had two major consequences for Missouri River management decisions. First, it dedicated upstream storage to three primary uses: hydropower generation, navigation enhancement, and flood control. Second, it made the Corps the de facto mainstem river master and reduced the influence of other federal agencies in mainstem management issues. The act's key provisions included:

> a. declared the Congressional policy to recognize rights and interests of states in water resources development and the requirement for consultation and coordination with affected states.
>
> b. required the Corps to coordinate with the U.S. Department of the Interior in cases of waters rising west of the ninety-seventh meridian.
>
> c. authorized provision of recreation areas for public use, including recreation and fish and wildlife conservation.
>
> d. assigned the Secretary of the Army responsibility for prescribing use of storage allocated for flood control or navigation in all reservoirs constructed wholly or in part with federal funds, and
>
> e. authorized the Corps to include irrigation as a project purpose in the 17 western states.

The Act also includes the following language inserted by Senators Joseph O'Mahoney (Wyoming) and Eugene Millikin (Colorado) that guarantees the upper basin states a priority to use water for irrigation:

> The use for navigation, in connection with the operation and maintenance of such works herein authorized for construction, of waters arising in States lying wholly or partly west of the ninety-eighth meridian shall be only such use as does not conflict with any beneficial consumptive use, present or future, in States lying wholly or partly west of the ninety-eighth meridian, of such waters for domestic, municipal, stock water, irrigation, mining, or industrial purposes. (33 U.SC. 701-1.)

Since approval of the Flood Control Act of 1944, the Corps has operated the mainstem system in accordance with its understanding of competing needs in the basin, its responsibilities described in navigation and flood-control legislation, and in response to congressional committee instructions. Although the Bureau of Reclamation initially sought to establish a centralized basin-control system, it eventually acceded to Corps control

Box 2.2
U.S. Water Resources Management and Science Organizations in the Missouri River Basin

Army Corps of Engineers—Responsible for flood-damage reduction activities and navigation-enhancement activities; also involved in ecosystem restoration activities. The Corps constructed and operates thousands of dams across the nation, and it constructed and operates six mainstem dams on the Missouri River.

Bureau of Reclamation—Responsible for water resources development and management activities in the 17 western (contiguous) U.S. states (i.e., those that straddle the one-hundredth meridian and westward). The Bureau constructed and operates the Canyon Ferry Dam on the Missouri River, along with many other dams across the western United States.

Environmental Protection Agency—Water-related responsibilities include establishing drinking water quality standards, wastewater management, and wetlands, oceans, and watersheds. EPA jointly administers (with the Corps of Engineers) the Clean Water Act's Section 404 program. EPA also monitors progress of national programs for total maximum daily load pollutants and for reducing nonpoint source pollution.

Federal Emergency Management Agency—Administers the National Flood Insurance Program, which provides flood insurance to communities that agree to assure that future floodplain structures meet safe standards. FEMA also conducts other flood hazard mitigation, response, and recovery activities.

Federal Energy Regulatory Commission—Responsible for reviewing, relicensing, and decommissioning federally licensed hydroelectric power dams.

Fish and Wildlife Service—Major responsibilities involve migratory birds, endangered species, certain marine mammals, and freshwater and anadromous fish. A

because its proposed reclamation agenda had not been realized. Only the responsibility for tributary operations was left to the agency responsible for specific project construction. As the mainstem dams were completed and their reservoirs filled, the Corps assigned operation of the system to its Reservoir Control Center in Omaha, Nebraska, where it remains today.

In 1953, to provide opportunities for coordination with the states and the other federal agencies, the Corps established a Coordinating Committee on Missouri River Mainstem Operations. This committee functioned for nearly three decades. In 1982, because the newly passed Federal Advisory Committee Act (FACA) created administrative requirements for the committee's operation and limited its ability to operate in executive session, and therein to forge consensus positions, the committee agreed to dissolve. The Corps announced that in place of the committee it would conduct semiannual public meetings to provide information about important water development issues. The Corps has also solicited comments on proposals for changes to dam and reservoir operations.

major function is the identification and recovery of endangered species. Under the Endangered Species Act, the Service identifies species that appear to be endangered or threatened. The Service consults with other federal agencies and renders "biological opinions" on the effects of proposed federal projects on endangered species.

Forest Service—Manages federal "Wild and Scenic rivers" and manages national forest lands to promote watershed protection.

Geological Survey—Conducts scientific programs in several areas of water resources, including streamflow gauging, groundwater monitoring, water quality assessment (the USGS oversees the National Water Quality Assessment Program, or NAWQA), and ecosystem monitoring through its Biological Resources Division.

National Park Service—Has regulatory and planning responsibilities on National Park lands. The Missouri basin contains dozens of national parks and national monuments.

Natural Resources Conservation Service (formerly the Soil Conservation Service)—Promotes land-use management practices aimed toward reducing erosion and promoting conservation. NRCS seeks to reduce the risks of floods and droughts in the nation's watersheds.

Tribal Governments—Native American tribes have federal public trust rights and responsibilities on their reservations. The Mni Sose organization represents 28 of the Missouri Basin's Native American tribes in basinwide water policy discussions and formulation.

Western Area Power Authority—Markets and delivers hydroelectric power and related services within a 15-state region of the central and western United States, including most of the Missouri River basin. WAPA, one of four power marketing administrations within the U.S. Department of Energy, markets electricity from Bureau of Reclamation and Corps of Engineers hydropower dams.

Since Pick–Sloan, the Corps has emerged as the Missouri River water master, although the river must be managed in the context of a larger suite of federal, state, and tribal laws. The Corps' role as the key federal agency in Missouri River management has been facilitated because there are relatively few private or public entitlements on the mainstem which conflict with its policies. No private individual or state "owns" the flow of the Missouri. Each basin state can claim an equitable share by Supreme Court degree, interstate compact, or Congressional action, but the Missouri has never been apportioned by any of these methods. The federal "navigation servitude" posits that no individual may assert a property right to the flow of a navigable river below the high water mark, but private entities and tribes may obtain a right to use a portion of the flow (individual water rights are described in Box 2.3). Because firm private and tribal rights exist primarily on the tributaries (with the exception of Montana), the Missouri is most accurately characterized as a regulated river, rather than a fully allocated one.

Box 2.3
Water Rights in the Missouri River Basin

State Use Entitlements. Each riparian state is entitled to an equitable share of the river, but the right must be based on prior or reasonably anticipated use. The rights can be firmed up by Supreme Court decree, interstate compact, or congressional apportionment. The states have explored these options, but they have not been implemented. In the 1980s, the Supreme Court rejected an original action that asserted that the Pick–Sloan Plan was a congressional apportionment. Article III, Section 2 of the U.S. Constitution provides that suits by one state against another state must be filed directly in the Supreme Court rather than in a lower federal court. In practice, the Supreme Court appoints a special master to take evidence and prepare a recommended decision, and the Court hears arguments by those who object to the special master's report.

Individual Use Rights. Colorado, Montana, North Dakota, South Dakota, and Wyoming follow prior appropriation and allow an individual to perfect a right based on diversion and application to beneficial use. Iowa and Missouri recognize common law riparian rights and permit rights. Riparian rights exist by virtue of ownership of land adjacent to a stream and do not depend on actual use. Kansas is now a pure appropriation state. Nebraska is a dual state and recognizes both riparian and appropriation rights.

Rights of Indian Tribes. Indian tribes may claim group rights that have both riparian and appropriative characteristics. Based on the Winters Doctrine of 1908, federal reserved water rights arise by virtue of the creation of a reservation. These rights date from the date of the creation of the reservation (or perhaps time immemorial if they are true aboriginal rights) and do not depend on the application of water to beneficial use. However, the rights have been primarily recognized for irrigation and have not been of great benefit to the Missouri River tribes.

KEY DEVELOPMENTS FOLLOWING PICK–SLOAN

Pick–Sloan was enacted at the height of the Reclamation Era, before the project's environmental consequences were clearly understood and before the environmental movement of the 1960s. Many fish and wildlife professionals understood the possible adverse consequences of dams for fish. As early as 1934, Congress enacted the Fish and Wildlife Coordination Act, which mandated that fish conservation be given equal treatment with other project purposes. However, the act did not substantively influence dam construction or operation, except to provide the legal basis for fish ladders and stocking programs. Beginning in 1969, Congress began to enact a series of environmental protection laws that imposed new duties on federal water resources management agencies.

Three key laws require the incorporation of environmental values into

Regulatory Rights. The federal government can mandate flows for environmental protection purposes. These flows supercede state-created water rights.

Navigation Rights. The "navigation servitude" posits that no individual may assert a property right to the flow of a navigable stream below the stream's high-water mark. The assumption has long been that the government may enhance or destroy the navigable capacity of a stream. In a February 1988 decision (ESTI Pipeline Project v. Missouri, 484 U.S. 495, 1988), the Supreme Court gave the Corps great discretion to make decisions about Missouri River flow management. However, the status of navigation is complicated by the O'Mahoney–Millikin compromise, which the upper basin states argue subordinates navigation to irrigation and precludes the recognition of any vested rights for a navigation channel depth.

Flood Protection Rights. The federal government is not liable for "acts of God" and is immune from all liability arising from the operation of flood-control reservoirs (33 U.S.C. Section 702c). This committee was not aware of any case alleging that the federal government is liable for flood damage when it subordinates flood control to environmental protection objectives. The assumption is that if the government inundates land above the high-water mark in connection with a flood-control project, the government must compensate the landowner. But this assumption must be qualified.

The Supreme Court recently limited the federal government's immunity for flood damage. Immunity is now based on the function of the release that did the damage rather than on the source of the release. Thus, if the water is released from a multiple-purpose reservoir for a non-flood control objective such as irrigation, the federal government will be liable for the resulting *damage* (Central Green Co. v. United States, 531 U.S. 1999). This decision opens the possibility that land owners injured by reservoir releases unrelated to any flood-control objective may recover damages from the federal government.

dam and reservoir operations. The National Environmental Policy Act of 1969 requires the preparation of environmental impact statements (EIS) for all major federal actions that will significantly affect the quality of the environment. This act has been interpreted as to not apply to pre-1969 dam operating plans [Upper Snake River Chapter of Trout Unlimited v. Hodel, 706 F. Supp. 737 (D. Idaho 1989), aff'd, 921 F. 2d 232 (9th cir. 1990)]. But new actions such as the preparation of new operating guidelines, structural changes to a dam or power plant, are likely to trigger a full environmental impact statement on operations, as compared to simply the existence of the dams.

The Clean Water Act of 1972 imposes technology-forcing standards on all point sources of pollution. An important federal circuit court appeals decision held that dams were not point sources [National Wildlife Federation v. Gorsuch, 693 F. 2d 156 (D.C. Cir. 1982)], but this case is not likely the last word on the issue.

The Endangered Species Act of 1973 has the greatest potential to mandate changes in dam and reservoir operations. Unlike NEPA, the mandates of the statute are substantive rather than procedural. The act permits the Department of the Interior to list species as endangered or threatened. Once a species is listed, no federal agency may take an action that jeopardizes the continued existence of the listed species or that modifies its critical habitat. Specifically, the federal agency must consult with the U.S. Fish and Wildlife Service. If the U.S. Fish and Wildlife Service decides that the federal action is likely to jeopardize the continued existence of the species, it will prepare a biological opinion, which documents the likely impacts of the action and suggests reasonable and prudent alternatives and possible mitigation measures. In practice, the consultation process has turned into a permit process rather than a veto process over federal actions. Nonetheless, the Endangered Species Act is both an important consideration in water management decisions and an additional source of discretion for altering traditional water management policies.

The Master Manual

The impacts of NEPA, the Clean Water Act, and the Endangered Species Act are reflected in the current controversy over proposed revisions to the Corps' Missouri River Main Stem System Reservoir Regulation Manual (Master Manual), which was first prepared in 1960 by Corps staff in Omaha. The Master Manual is the primary guidance document for operation of the mainstem reservoirs and reflects the Corps' interpretation of its statutory responsibilities and operating approaches developed in coordination with state agencies and other federal agencies. The Master Manual codified the practices that had developed over the previous decade (Ferrell, 1993). Although it does not define specific operating priorities, the Master Manual does provide general guidance for dealing with conflicts among uses (section 9-3):

> The following general approach which was developed and generally agreed upon during planning and design of the reservoirs, is observed in operation planning and in subsequent reservoir regulation procedures:
>
> First, flood control will be provided for by observation of the requirement that an upper block of this intermediate storage space in each reservoir will be vacant at the beginning of each year's flood season, with evacuation scheduled in such a manner that flood conditions will not be significantly aggravated if at all possible (this space is available for annual regu-

> lation of flood control and all multiple purpose uses but should be vacant at the beginning of each flood season).
>
> Second, all irrigation and other upstream water uses for beneficial consumptive purposes during each year will be allowed for. This allowance also covers the effects of upstream tributary reservoir operations, as anticipated from operating plans for these reservoirs or from direct contact with operating agencies.
>
> Third, downstream municipal and industrial water supply and water quality requirements will be provided for.
>
> Fourth, the remaining water supply available will be regulated in such a manner that the outflow from the reservoir system to Gavins Point provides for equitable service to navigation and power.
>
> Fifth, by adjustment of releases from the reservoirs above Gavins Point, the efficient generation of power to meet the area's needs consistent with other uses and power market conditions will be provided for.
>
> Sixth, insofar as possible, without serious interference with the foregoing functions, the reservoirs will be operated for maximum benefit to recreation, fish and wildlife.

To supplement the Master Manual, the Corps each year prepares a more detailed Annual Operating Plan (AOP). During its existence, the Coordinating Committee on Missouri River Mainstem Operations provided input to the Annual Operating Plan. Since then, semiannual public meetings provide opportunities for public and governmental input.

MISSOURI RIVER RESERVOIRS AND DAMS

Dam and Reservoir Operations

The Missouri River mainstem reservoir system consists of six major dams and reservoirs (Photos 2.1 through 2.6). The reservoirs differ greatly in storage and discharge capacity, shoreline length, and drainage area characteristics (Table 2.2).

For purposes of reservoir management, modeling, and decision-making, these reservoirs are divided into different conceptual levels, or zones. Figure 2.4 shows these conceptual zones, how they are divided according to the authorized uses in the system, and the capacities of each. Table 2.3 shows more detailed information about the capacities of these zones in the six mainstem reservoirs operated by the Corps.

Authorized purposes for these reservoirs include:

- *Flood Damage Reduction*. The high-risk season for flooding in the Missouri River system, March until mid-summer, coincides with the poten-

PHOTO 2.1 Fort Peck Dam (from Corps of Engineers Digital Visual Library http://images.usace.army.mil/)

PHOTO 2.2 Garrison Dam (from Corps of Engineers Digital Visual Library) http://images.usace.army.mil/

PHOTO 2.3 Oahe Dam (from Corps of Engineers Digital Visual Library)

PHOTO 2.4 Big Bend Dam (from Corps of Engineers Digital Visual Library http://images.usace.army.mil/)

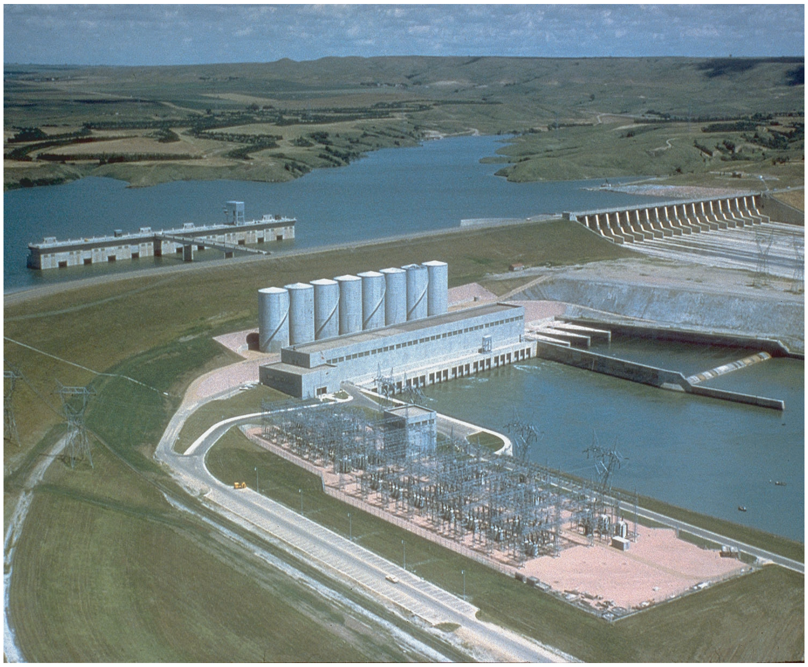

PHOTO 2.5 Fort Randall Dam (from Corps of Engineers Digital Visual Library http://images.usace.army.mil/)

PHOTO 2.6 Gavins Point Dam (from Corps of Engineers Digital Visual Library http://images.usace.army.mil/)

TABLE 2.2 Missouri River Reservoir Features

Reservoir (1)	Storage capacity (1,000 acre-feet) (2)	Maximum discharge capacity (cubic feet per second) (3)	Lake shoreline length (miles) (4)	Cumulative drainage area upstream (square miles) (5)	Cumulative average annual inflow upstream (cfs) (6)
Fort Peck Lake	18,688	291,000	1,520	57,500	10,200
Garrison Dam/ Lake Sakakawea	23,923	796,000	1,340	181,400	25,600
Oahe Dam/ Lake Oahe	23,338	245,000	2,250	243,490	28,900
Big Bend Dam/ Lake Sharp	1,874	373,000	200	249,330	28,900
Fort Randall Dam / Lake Francis Case	5,574	680,500	540	263,480	30,000
Gavins Point Dam / Lewis and Clark Lake	492	381,000	90	279,480	32,000

SOURCE: USACE, 1989.

tial occurrence of snowmelt, ice jams, or heavy rainstorms. The Corps divides the storage capacity of each reservoir into zones, or pools (Figure 2.4), and reserves space in each reservoir for flood control. Table 2.4 shows the flood control storage volume reserved in each reservoir, and also shows additional reservoir storage in the system allocated for other project purposes.

- *Water Supply and Irrigation.* One of the authorized purposes of the mainstem reservoir system is to supply water for municipalities, industries, and irrigation throughout the basin. Irrigation was an integral component of the original system planning and design, pumps, diversions, and other water distribution facilities were planned and constructed to move water to farms in the basin. However, as Sveum (in Benson, 1988) noted,

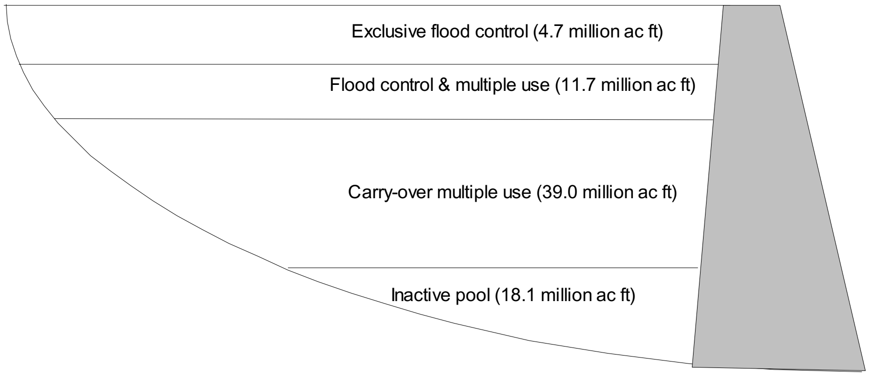

FIGURE 2.4. Missouri River system reservoir storage allocation (values shown represent cumulative capacity of the six main-stem reservoirs).
SOURCE: USACE, 1989.

"lack of support and economic problems" have resulted in less than anticipated demand for water from Lake Sakakawea (Garrison Diversion Unit) and from the irrigation development at Oahe Dam. The latter was deauthorized and the former is not in full operation. Downstream from Sioux City, Iowa, 40 major municipal and industrial users depend on the Missouri River for water. Seventeen of the 40 users are municipalities that withdraw water for approximately 3.2 million people, 21 are power plants that withdraw water for cooling, and 2 are chemical manufacturers (GAO, 1992).

- *Navigation*. The Missouri River navigation channel extends 735 miles upstream from the river's mouth at St. Louis to Sioux City, Iowa. The Corps of Engineers' Navigation Data Center reports that total downbound shipping in 1999 was 4.29 million tons and upbound shipping was 4.72 million tons (http://www.wrsc.usace.army.mil/ndc/). Shipping is seasonal and it typically extends from late March until late November or mid-December. During the remainder of the year, the possibility of ice blockage and floating ice prevents commercial navigation. Releases are made from the system reservoirs to support navigation. Fort Peck, Garrison, and Oahe dams provide about 88 percent of the total water storage capacity and thus play a significant role in supporting navigation. The multiple use zones in the reservoirs store water from year to year to support navigation when water in the annual operating zone is exhausted.
- *Hydropower*. All reservoirs have facilities for hydropower generation, and the sale of the energy is a major revenue-producing system purpose. Installed power generation capacity of the reservoirs is shown in

TABLE 2.3 Missouri River Reservoir Operational Zones

Zone (1)	Use (2)
Exclusive flood control	...top zone in each reservoir...utilized only for detention of extreme or unpredictable flood flows, and is evacuated as rapidly as feasible within limitations imposed by considerations for flood control...[which] include project release limitations, status of storage in other main stem projects and the level of system releases being maintained...
Flood control and multiple use	...reserved annually for retention of normal flood flows and for annual multiple-purpose regulation of the impounded flood waters...this zone...will normally be evacuated to a predetermined level by about 1 March to provide adequate storage capacity for the flood season...evacuation of the flood control and multiple use storage capacity is scheduled to maximize service to the conservation functions.
Carry-over multiple use	...provides a storage reserve for irrigation, navigation, power production, and other beneficial conservation uses. At the major projects (Ft. Peck, Garrison and Oahe) the storage space in this zone will provide carry-over storage for maintaining downstream flows [for] below normal runoff years. It will be used to provide annual regulation in the event the storage in the annual flood control and multiple-use zone is exhausted.
Inactive	...provides minimum power head and sediment storage capacity. It also serves as a minimum pool for recreation, fish and wildlife, and assured minimum level for pump diversion of water from the reservoir...drawdown into this zone will not be scheduled except in an unusual emergency.

SOURCE: USACE, 1979.

Table 2.5. The Western Area Power Administration markets and transmits the power generated by the Missouri River reservoir system.

- *Fish and Wildlife*. The Master Manual requires that ". . . the reservoirs will be operated for maximum benefit to recreation, fish and wildlife" to the extent possible, without interference with other project purposes. The manual acknowledges that fish production and development below the main stem projects are affected by reservoir levels and releases and makes provisions for operation of selected reservoirs to improve fishery

TABLE 2.4 Storage in Missouri River System Reservoirs

Reservoir (1)	Exclusive flood control storage (1,000 ac ft) (2)	Flood control and multiple use storage (1,000 ac ft) (3)
Fort Peck	974	2,718
Garrison	1,494	4,220
Oahe	1,097	3,186
Big Bend	60	117
Fort Randall	985	1,322
Gavins Point	60	92

SOURCE: USACE, 1989.

TABLE 2.5 Hydropower Generation Capabilities of Missouri River Mainstem Reservoirs

Reservoir (1)	Dependable capacity (kW) (2)	Average annual energy (10^6 kWh) (3)
Fort Peck	181,000	1,044
Garrison	388,000	2,354
Oahe	534,000	2,694
Big Bend	497,000	1,001
Fort Randall	293,000	1,745
Gavins Point	74,000	700

SOURCE: USACE, 1989.

resources. For example, the Corps reported that on April 28, 2000, releases at Garrison Dam were reduced from 20,000 to 18,000 cubic feet per second to keep the reservoir level from falling during the smelt spawning period (Joe Pletka, U.S. Army Corps of Engineers, personal communication, 2001). Even though the inflow into upstream reservoirs was at that time well below normal, this regulation provides for stable pools at both Lake Oahe and Lake Sakakawea. Similarly, the Master Manual acknowledges a need to operate the reservoirs for improving migratory waterfowl habitat.

- *Recreation*. Public Law 78-534 or Public Law 99-662 authorize operation of the mainstem reservoirs for recreation. The Corps' Summary of Actual 1999–2000 Operations report shows that during fiscal year 2000, public use at the mainstem lakes was more than 60 million visitor hours.

Recreational uses are particularly important at lakes Sakakawea, Oahe, Francis Case, and Lewis and Clark.

Operational Procedures

Operational guidelines

The system reservoirs are operated following guidelines in a set of six individual reservoir regulation manuals and in the Master Manual. The individual reservoir regulation manuals describe how features of each reservoir that are not common to the system as a whole are to be operated, while the Master Manual prescribes the allocation of water and storage among the system's hydraulically interconnected reservoirs.

Interpretation and Operation According to Guidelines

The Reservoir Control Center (RCC) of the Corps' Northwestern Division in Omaha, Nebraska is responsible for interpreting the Master Manual guidelines and transforming the guidance into daily decisions about appropriate amount of water to release and store in the system's reservoirs. System operation is guided by the Master Manual on two time scales:

A seasonal scale stipulates storage and discharge targets for system water control. In terms of serving navigation, for example, the Master Manual stipulates that if the cumulative system storage as of March 15 each year is 54.5 million acre-feet or more, then the coordinated system should be operated to provide an average flow of 31,000 cubic feet per second at Sioux City, Iowa between March 23 and November 22 (USACE, 1979). Further, the seasonal guidelines require cumulative storage to be examined on July 1 each year to determine if the navigation season should be shortened. For example, if the cumulative storage on July 1 is 25 million acre-feet or less, support of the navigation season will terminate on September 7, rather than on November 22. Similar guidance in the Master Manual stipulates minimum daily flow requirements to maintain suitable downstream water quality each month at Sioux City, minimum releases for water supply, and so on.

A daily-hourly scale determines actual storage and discharge values as a function of current availability and demands. Although the Master Manual provides guidance for system and individual reservoir operations, the Corps' Reservoir Control Center staff in Omaha determines individual dam releases for all daily purposes, (or in the case of flood operations, hourly), based upon current conditions and projected inflow in the short term. For example, the Master Manual calls for operation immediately following a flood with the following priorities:

1. Evacuation of surcharge storage from all reservoirs;
2. Evacuation of exclusive flood-control storage in Lewis and Clark, Francis Case, and Sharpe lakes;
3. Evacuation of exclusive flood-control storage in Fort Peck, Sakakawea, and Oahe lakes;
4. Evacuation of annual flood-control and multiple-use storage in Lewis and Clark and Francis Case lakes' annual flood-control and multiple-use storage space above elevation 1360;
5. Evacuation of annual flood-control and multiple-use storage in Fort Peck, Sakakawea, and Oahe lakes.

But even with such specificity, actual releases and storages are not prescribed outright by the Master Manual or individual reservoir regulation manuals. Instead, the Reservoir Control Center staff reviews, on a daily or hourly basis, forecasts of future rainfall and runoff and observations of current conditions in the basin (including current storages and releases, uncontrollable inflows to the river in reaches between reservoirs, and current flooding at critical points). They then select actual releases to be made. This is complicated by the inability to perfectly forecast future inflows, and further complicated by the hydraulic interconnections of the reservoirs, as any outflow from an upstream reservoir is inflow to a downstream reservoir. The problem is thus not a simple problem of accounting for the inflow to, outflow from, and change in storage in a single reservoir. Instead, it is a problem of simultaneously finding the outflows from all reservoirs in the system to best achieve the system operation objectives—a set of objectives that is the subject of much disagreement.

The drought of the late 1980s stretched the Corps' ability to meet the variety of mainstem water demands, and the Corps ultimately decided to review the Master Manual. At the same time, the Missouri River basin states expressed concerns over priorities being assigned by the Corps to various water uses. Recreation and fish and wildlife interests argued that priority in water use for a dwindling navigation program was at their expense and represented an anachronism. The U.S. Fish and Wildlife Service asked the Corps to more carefully consider threatened and endangered species in its operations. As a result, the Corps in 1989 announced that it would conduct a major review of the Master Manual. Thirteen years later, this review is still under way. Several proposals have been offered by the Corps but have been quickly rejected by one or more of the interested parties.

In 1989, the Corps and the U.S. Fish and Wildlife Service began a series of consultations mandated by the Endangered Species Act. In 1990 and 1994, the Fish and Wildlife Service issued biological opinions indicating that actions proposed by the Corps would place certain species in jeopardy. On receipt of these opinions, the Corps continued to develop alternative approaches to system operations. In April 2000, the Corps requested the Fish and Wildlife Service to formally consult on the operations of the Missouri River mainstem system, related operations of the Kansas River tributary reservoirs, and on the operations and maintenance of the Missouri River Bank Stabilization and Navigation Project. The Fish and Wildlife Service concluded that continuation of current operations on the Missouri River was likely to jeopardize the continued existence of several listed species. In November 2000, the Corps' Northwestern Division Engineer discussed the Corps position on the biological opinions of the Fish and Wildlife Service:

> There is significant agreement between the Corps and Service on the known biological attributes necessary to recover the listed species. . . . The Corps is absolutely committed to its role in recovery of the listed species but we also have an obligation to support other project purposes. . . . Our initial assessment is that elements of the biological opinion slightly increase the risk of flooding and are detrimental to navigation. As we develop our implementation plan we will evaluate the impact of the reasonable and prudent alternative on these and other project purposes. It is possible that the Corps will propose an alternative that meets the biological objectives with reduced impacts in other areas (Strock, 2000).

The consultation continued at this report's preparation.

> The Corps' historic response to the consequences of its reservoir operations on fish and wildlife habitat has been to mitigate these consequences through a variety of means including habitat acquisition and restoration, enhancement of flows through side channels, and development of backwater areas.

COMMITTEE COMMENTARY

Water resources development activities in the Missouri River basin started nearly two centuries ago, soon after the Lewis and Clark expedition. These activities occurred when a national objective was to develop the natural resources of the western United States and to promote settlement. The Missouri River and its floodplain provided water, food sources, fertile agricultural lands, and a transportation corridor. Huge floods that resulted in losses of life and property were typical of the pre-regulation Missouri River.

During the nineteenth century, there was an emphasis on encouraging settlement in the Missouri River basin and other parts of the West. The promotion of irrigation thus became a national policy that was reflected in federal laws such as The Homestead Act of 1862 and the Reclamation Act of 1902. Native Americans were given little or no consideration in the political planning processes for Missouri River development.

The Great Depression of the 1930s and a pronounced drought in the Midwest and Great Plains during this period had major impacts on the basin. The Fort Peck Dam was built as a Public Works Administration project to provide jobs and to promote navigation. At the same time, the Bureau of Reclamation was planning and developing irrigation and hydropower projects on Missouri River tributaries. During the same period, the Corps was considering flood-control dams for the basin. After congressional approval of the Pick–Sloan Plan, the Corps built five mainstem dams and assumed principal responsibility for operating them.

The chain of Missouri River reservoirs and dams from Montana to South Dakota is one of the twentieth century's engineering marvels. The dams' modernistic architecture and their powerhouses testify to what was once a nearly unlimited faith in the ability of technology to bring progress to society. Pick–Sloan reflected the then almost universal faith in large dams to support and sustain regional development in areas not favored by climate and geography, and also not favored by the era's unique political and social conditions. The Great Depression of the 1930s revived the construction of multiple-purpose dams begun during the Progressive Conservation Era in the first two decades of the century. Hopes of settling returning World War II veterans on family farms in the upper basin and the need to provide civilian jobs for the veterans excited planners and politicians. The merging of the Corps' and the Bureau of Reclamation's plans into the final Pick–Sloan Plan in a sense represented a marriage contract between two of the world's most powerful water development agencies. Over the next two decades, much of the Pick–Sloan Plan was implemented to help realize a powerful vision, but one that was not fully attained. The dams and reservoirs only partially fulfilled their promise. Many citizens today are thus calling for a more comprehensive and balanced vision of the river's role in the basin.

The legal framework for the Missouri also changed with the emergence of environmental protection as a national goal. Virtually all of the nation's environmental laws have been enacted since the initial decisions were made on Missouri River mainstem dam operations and priorities. Specific examples include the strengthened Fish and Wildlife Coordination Act of 1958, the National Environmental Policy Act of 1969, and the Conservation, Protection, and Propagation of Endangered Species Act of 1973. When the mainstem dams were constructed, there was minimal consideration of environmental impacts. Since then, there has been a shift in emphasis in the United States from the development of water resources to better management of water resources in highly developed, mature systems like the Missouri River, and specifically to explore the prospects for restoring some level of ecosystem benefits that have often been diminished with river regulation. As there have also been large social and economic changes in the Missouri Basin over the past half-century, there is a clear need for a comprehensive review of operational priorities of the Missouri River dams that better reflects twenty-first century values and scientific knowledge.

The lack of a well-structured, flexible, and updated mechanism for coordinating the current interests of the Missouri River basin states, tribes, federal and state agencies, and nongovernmental parties with stakes in dam and reservoir operations represents a barrier to resolving differences and improving environmental and operational conditions. The inability of basin stakeholders to reach consensus has made it difficult to arrive at an approach to river operations that will meet contemporary and future needs in the basin. This matter must be addressed in order to preserve the Missouri River ecosystem and to produce a broader range of ecosystem benefits formerly provided by the river.

3

Missouri River and Floodplain Ecology

I observe a great alteration in the Current course and appearance of this pt. of the Missouri. in places where there was Sand bars in the fall 1804 at this time the main current passes, and where the current then passed it is now a Sand bar. Sand bars which were then naked are now covered with willow several feet high. the enterance of some of the Rivers & creeks changed owing to the mud thrown into them, and a layor of mud over some of the bottoms of 8 inches thick.

Captain William Clark, August 20, 1806

The Missouri River ecosystem experienced a marked ecological transformation during the twentieth century. At the beginning of the century, the Missouri River was notorious for large floods, for a sinuous and meandering river channel that moved freely across its floodplain, and for massive sediment transport. But by the end of the twentieth century, the Missouri River bore little resemblance to the previously wild, free-flowing river. This chapter describes these environmental changes in the Missouri River ecosystem, contrasting the ecological state of the river and its floodplain before and after the construction of the series of large mainstem dams and reservoirs. The physical and ecological units of today's Missouri River ecosystem are then described, followed with a review of the scientific research that forms the basis for our understanding of the ecosystem's dynamics and the consequences of human actions. The chapter concludes with an overview of the system's ecological issues and a commentary from the committee.

Seven huge dams were constructed along the Missouri River during the twentieth century, six of them pursuant to the 1944 Pick–Sloan legislation. The river's annual flooding regime was nearly eliminated in those areas under the dam's controlling influences. In another key twentieth century environmental change, the river was confined to a single, uniform channel. It was fixed in place by dikes and revetments downstream from just below

Gavins Point Dam, the most downstream dam, to the river's mouth at St. Louis.

Ecological changes that accompanied changes in hydrology proceeded more slowly but were of a similar magnitude. Large floodplain areas along the upper Missouri were inundated by the reservoirs. Large areas of native vegetation communities in downstream floodplains were converted into farmland. Many native fish and avian species experienced substantial reductions, while nonnative species—especially fishes—thrived in some areas.

Scientists and citizens today understand more fully the consequences of similar changes that have occurred on many of the world's large rivers and the possibilities for reversing them. In the second half of the twentieth century, the field of large river ecology emerged to provide a scientific basis for river restorations, strategies, and initiatives. This research and the scientific understanding of river ecosystems builds upon a longer history of research on hydrology, geomorphologic processes (the shaping of river channels by water and sediment), vegetation dynamics, and river mechanics. The importance of extreme climatic events in the ecological structure and functioning of large river-floodplain ecosystems features prominently in contemporary river science theories (Bioscience vol. 45, # 3, 1995). Recent studies of large river systems emphasize the ecological values of hydrologic connections between a river's main channel, backwaters, and floodplain (Gore and Shields, 1995; USGS, 1999; Ward and Stanford, 1995). Aquatic ecosystem restoration practices build upon and complement these theories. For example, current science-based river management paradigms and practices seek to take advantage of the tendency of these large river systems, through natural processes like floods and the transport of sediment, to make and sustain these connections (Bayley, 1995; USGS, 1999). Restoring some ecological functions of a large river system also provides the benefits of maintaining species biodiversity in the river and on its floodplain, as well as restoring habitat for threatened and endangered species. This chapter introduces and explains concepts that underpin the theories and practices of contemporary large river science and restoration. This knowledge helps explain the ecological consequences of human-induced changes in the Missouri River ecosystem and provides the scientific basis for considering public policy decisions to improve ecological conditions.

THE PRE-REGULATION MISSOURI RIVER

Physical Processes: Hydrology and Geomorphology

During the period of westward expansion in the United States, the Missouri River was a large floodplain river. It periodically overflowed its banks and water spread across its floodplain, hydrologically connecting the channel, to its floodplain and backwaters. The Missouri River created new channels as its main channel moved laterally across its floodplain. These types of geomorphic changes in the channel were a notable feature of the pre-regulation Missouri, especially below present-day Yankton, South Dakota downstream to the confluence with the Platte River. In this stretch of the river, the distance between the Missouri River bluffs ranges from five to eighteen miles (Schneiders, 1999).

Variations in the river channel's location, form, and volume of sediment transported were driven by changes in river flows. In turn, the river's hydrology was greatly influenced by weather extremes. The annual pattern of flows on the pre-regulation Missouri included spring and summer rises that generally occurred in April and June, respectively. The April rise was caused by local snowmelt on the plains and by local rainfall; the June rise was caused by melting snowpack in the Rocky Mountains and rainfall at lower elevations. The spring rise tended to be brief, lasting about one to two weeks, and was relatively localized. The summer rise lasted longer and inundated larger portions of the floodplain.

Prior to regulation, the Missouri River was known as the "Big Muddy," as it carried large amounts of sediment. Erosion tended to be most severe as flood waters were rising, with substantial deposition of sediment occurring as flood waters receded. The Missouri River existed in a dynamic equilibrium with its floodplain, frequently redistributing sediment between its channel and floodplain, as described below.

As Missouri River flows increased in the spring and summer (referred to by hydrologists as the "rising limb" of a hydrograph), the river would erode sediment from its bed and its banks. The river bed would undergo rapid physical changes during this period; it would be degraded (lowered) because of erosion, the channel would migrate laterally, backwaters and the main river channel would be connected by overbank flows, and shoreline and riparian vegetation, including trees, would be scoured and washed into the channel. The rising water also would replenish the groundwater table, an important process for maintaining floodplain vegetation. As flows receded (the hydrograph's receding limb) and water volume and velocity decreased, the degraded channel would refill with deposited sediment, braided channels and meanders would become isolated from the main channel, and fresh substrates would be deposited for occupation by plants and animals.

Prior to channelization and flow regulation, the lower Missouri River was braided to highly sinuous, a form naturally found in rivers with broad floodplains and heavy sediment loads. Hiram Chittenden described the river's pre-regulation sinuosity in his account of the adventures of nineteenth century Missouri River steamboat captain Joseph La Barge:

> The river is like a great spiral stairway leading from the ocean to the mountains. A steamboat at Fort Benton is 2565 feet—two and one-times the height of the Eiffel Tower in Paris—above the level of the sea; yet so gentle is the slope nearly all the way that, in placid weather, the water surface resembles that of a lake. This wonderful evening-up of the slope of the river by the extreme sinuosity of its course is a fact not only interesting as a natural phenomenon, but of the utmost importance in the behavior and use of the stream (Chittenden, 1962).

The pre-regulation river was characterized by log jams, snags, whirlpools, chutes, bars, cut-off channels, and secondary channels around bars. The main channel typically had a deep thalweg (the deepest part of the river) that contained the faster-moving flow and a shallower section(s) on one or both sides of the channel (Figure 3.1). The cross-sectional shape of the main channel often exhibited a highly nonuniform velocity distribution (Hesse, 1993). The main river channel's width was variable, ranging from roughly 1,000 to 10,000 feet wide during normal flow periods to 25,000 to 35,000 feet wide during floods (Schneiders, 1999). Based on surveys completed between 1878 and 1892, the maps in figures 3.2 through 3.4 portray the sand bars, meanders, and extensive floodplain vegetation that characterized the pre-regulation riverine ecosystem at Bismarck, North Dakota, Yankton, South Dakota, and St. Joseph, Missouri, respectively.

River depth was greatest in spring and early summer and shallowest in December and January. However, there were scour holes downstream of

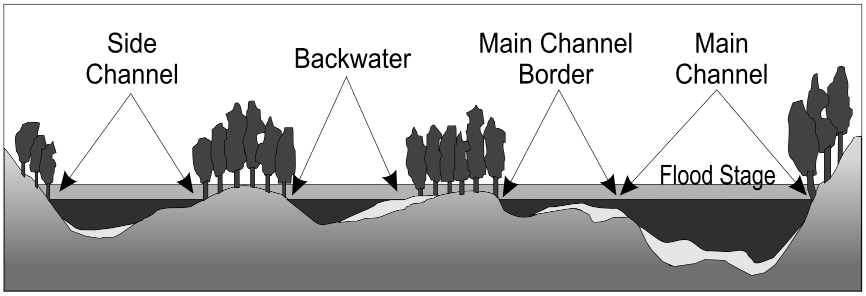

FIGURE 3.1 Typical cross-section of the pre-regulation Missouri River.
SOURCE: Rasmussen, 1999.

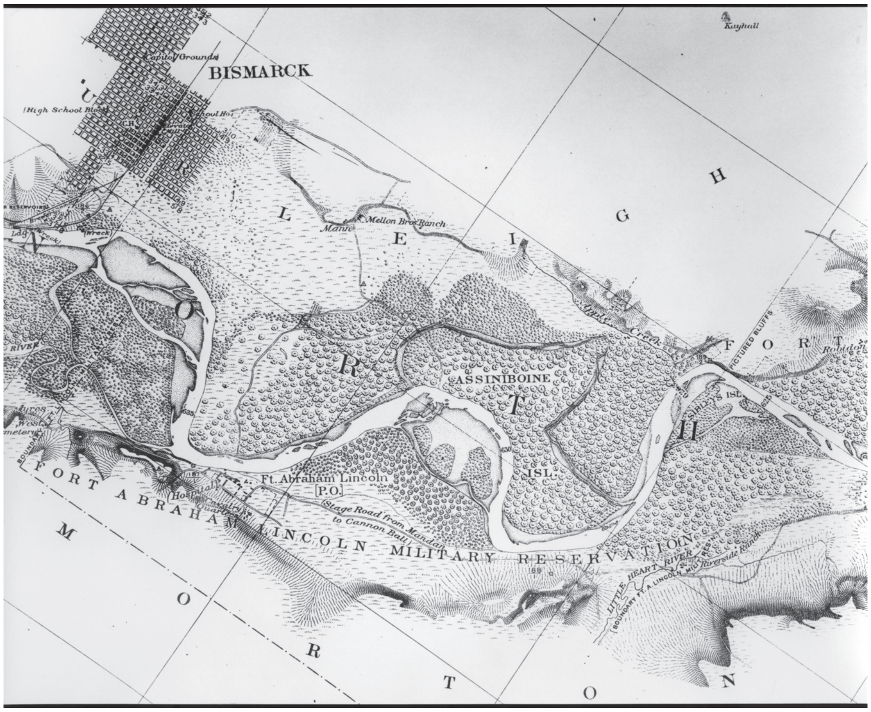

FIGURE 3.2 Nineteenth Century Missouri River Floodplain topography at Bismarck, North Dakota.
SOURCE: Hesse, 1987.

log jams and other obstructions, at bends, or where tributaries entered. Depths in these holes varied from a few inches to more than thirty feet (Schneiders, 1999). Mid-channel and point bars were found along the entire length of the Missouri River. The bars shifted frequently in response to changing flows with the larger bars scoured at higher flows.

Ecological Processes

The rich biodiversity (see Box 3.1) of the pre-regulation Missouri River ecosystem was sustained through a regime of natural disturbances that included periodic floods and attendant sediment erosion and deposition. These disturbances, in turn, supported a variety of ecological benefits, including commercial and recreational fishing, timber, biomass fuels, wild game, trapping and fur production, clean water, medicines, soil replenishment processes, and natural recharge of groundwater. The ecological pro-

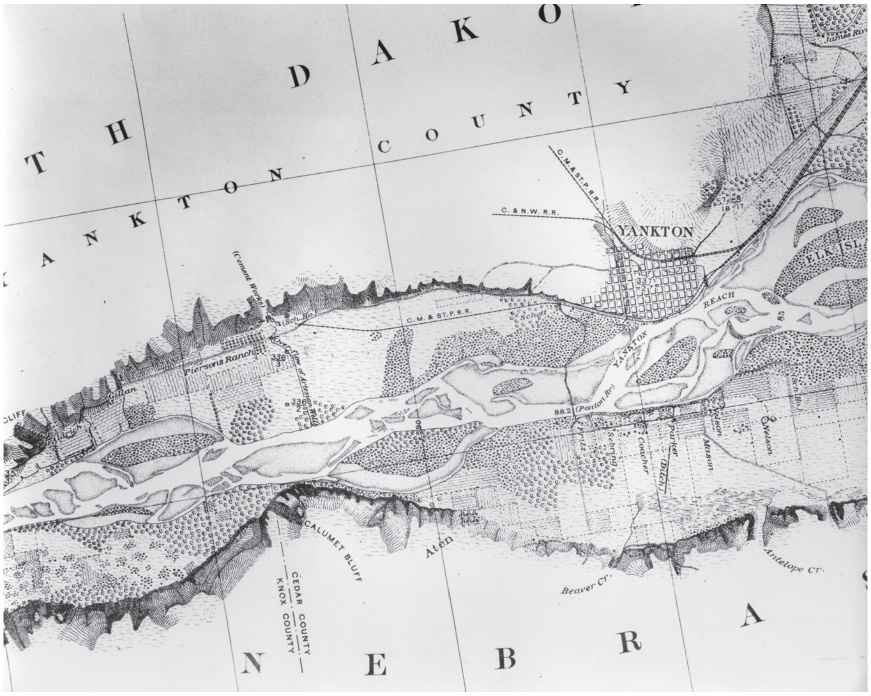

FIGURE 3.3 Nineteenth century Missouri River floodplain topography at Yankton, South Dakota.
SOURCE: Hesse, 1987.

cesses sustained by periodic flooding in river-floodplain ecosystems are encompassed by the contemporary concept known as “the flood pulse.”

The Flood Pulse Concept

The concept of the “flood pulse” summarizes the effects on biota of the connections between the river channel and floodplain (Junk et al., 1989; Bayley, 1995). The flood pulse describes the predictable rising and falling of water in a natural river-floodplain ecosystem as the principal agent controlling the adaptations of most of the biota. Central to the flood pulse concept is the notion that floods, rather than representing a disturbance to the ecosystem, are part of the natural hydrologic regime, and that the prevention of floods actually represents an ecological disturbance (Bayley, 1995). The flood pulse is essential to the health of river-floodplain ecosystems for the following reasons:

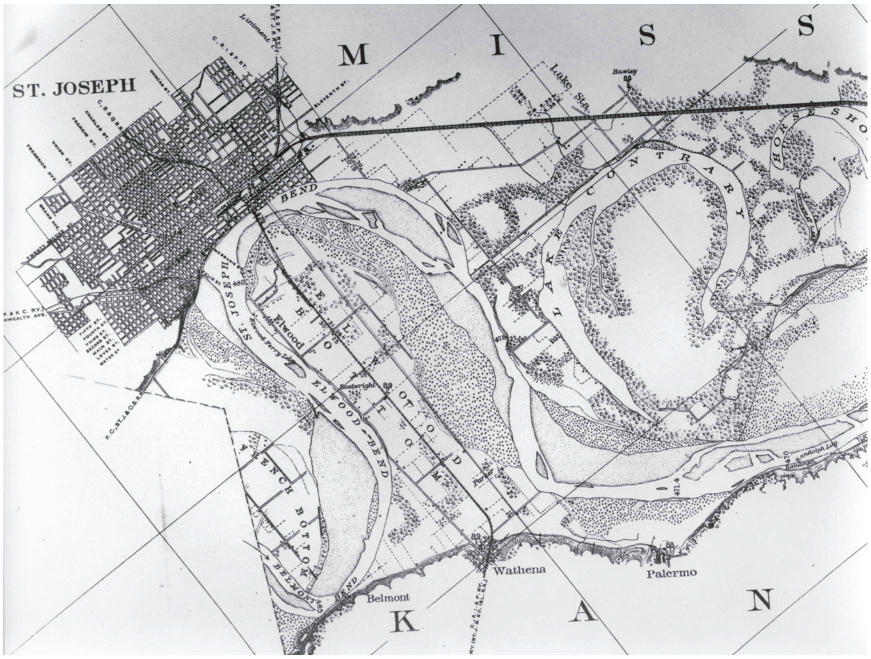

FIGURE 3.4 Nineteenth century Missouri River floodplain topography at St. Joseph, Missouri.
SOURCE: Hesse, 1987.

1. Floods add dissolved and particulate organic matter and mineral nutrients to aquatic and terrestrial ecosystems. The river channel and its floodplain both depend on erosion and deposition associated with the channel's lateral migration. Inundation deposits silts and nutrients that replenish floodplain pools and backwaters. The flooding of terrestrial mineral and organic matter releases nutrients to the water.
2. Many plants rely upon inundation for rapid growth and reproduction. Species such cottonwood and willow are highly dependent upon periodic floods.
3. Many animals (invertebrates, fish, birds, mammals) are adapted to the flood cycle and depend upon the high plant and microbial activity associated with it. Floods provide reproductive cues for many fish species in river-floodplain ecosystems. Furthermore, floods make inundated floodplain vegetation available as a food source for fish and invertebrates.

Box 3.1
Biodiversity

Biodiversity, the shortened term for *biological diversity,* is commonly used in the lexicon of twenty-first century environmental sciences. The Oxford Dictionary of Biology describes biodiversity as "the existence of a wide variety of species (*species diversity)* or other taxa of plants, animals, and microorganisms in a natural community or habitat, or of communities within a particular environment (*ecological diversity),* or of genetic variation within a species (*genetic diversity*). The maintenance of a high level of biodiversity is important for the stability of ecosystems." Biodiversity is often associated with the number and kinds of species at a locality. Ecologists describe the number of different species as species richness, while species diversity accounts for both the number of species as well as their relative abundance in a community. It is important to remember that biodiversity includes not only these components, but that it also refers to genetic diversity and may include all manner of organisms ranging from paddlefish to bacteria. Ecosystems that support high species diversity often also demonstrate high biodiversity, such that management for species diversity and species richness in natural ecosystems tends to foster the other, sometimes more obscure, elements of biodiversity. A key change that occurs in regulated river systems with respect to biodiversity is the proliferation of nonnative species. Described by Stanford et al. (1996) as the most pervasive result of habitat alteration in large regulated rivers, this shift usually occurs in communities ranging from fish and invertebrates to riparian and floodplain vegetation. A committee of the National Research Council (2000a) recommended that an indicator that measures *native species diversity* is an important indicator of human impacts on the environment.

Appreciation of the flood pulse's ecological significance has grown with recognition of the importance of flooding at various scales and magnitudes (Anderson et al., 1996; Wetzel, 2001). Key aspects of floods are frequency, duration, magnitude, and timing. The combination of these variables controls plant and animal life associations along rivers and influences all aspects of the riverine food web (Poff and Ward, 1989; Richter et al., 1996; Walker et al., 1995).

The timing of overflow is important to native biota adapted to life in rivers and adjoining riparian ecosystems. Periodic high flows and low flows help maintain the health of large river-floodplain ecosystems by acting as "reset" mechanisms that reinitiate early successional vegetation and serve to limit certain faunal associations that can outcompete species normally restricted to life within a channel (Cummins et al., 1984). Fish spawning, insect emergence, and seed dispersal are commonly triggered by rising waters that, once receding from the floodplain, provide food sources or seed beds for many riverine species.

Because these processes sustained the river's biological production and diversity, the pre-regulation Missouri River exhibited a rich heterogeneity of habitat. A typical cross-section of the pre-regulation Missouri River contained a deep channel, multiple side channels, oxbow lakes, islands, sand bars and dunes, and backwater habitats interspersed by areas of higher land. These channels and backwater areas provided slower-moving waters critical for the reproduction, shelter, and feeding of fish species. Higher lands contained rich forests, prairie grasses, and thick underbrush that contained a myriad of plant species. Lewis and Clark described this rich pre-regulation biodiversity, noting that the Missouri "nourishes the willow-islands, the scattered cottonwood, elm, sycamore, linden, and ash, and the groves are interspersed with hickory, walnut, coffee-nut, and oak" (Lewis and Clark expedition, Coues, editor; cited in Schneiders, 1999, p. 35).

THE POST-REGULATION MISSOURI RIVER

Physical Processes: Hydrology and Geomorphology

Flow regulation and channelization substantially changed the Missouri River's historic hydrologic and geomorphic regimes. The primary change was that the extreme high and extreme low flows were lost from the hydrograph downstream of each mainstem dam. This dampening effect below Gavins Point Dam extends downstream to near Nebraska City, Nebraska (Hesse, 1994), where tributary influences partially restore pre-regulation flows to the river. Below Fort Peck Dam, for example, the median high flow was cut in half following the dam's closure (Shields et al., 2000). Not only have high flows been markedly reduced in many areas, low flows have increased considerably. The result of these changes is an annual hydrograph that exhibits far less variability. Figures 3.5 and 3.6 show hydrologic changes in the post-regulation river at Sioux City, Iowa (just downstream of Gavins Point Dam) and at Hermann, Missouri. These figures illustrate hydrologic changes associated with the construction of the mainstem dams. The figures also show that these changes that occurred are not uniform along the Missouri River and that some downstream sections in the state of Missouri have experienced less hydrologic change with regulation. But the variability that characterized pre-regulation Missouri River hydrology has greatly diminished along most of the river—especially in those reaches directly below the dams—and the spring and summer rises no longer occur in many stretches.

The Missouri River also has experienced large changes to its channel structure and dynamics. The channelized portion of the Missouri River

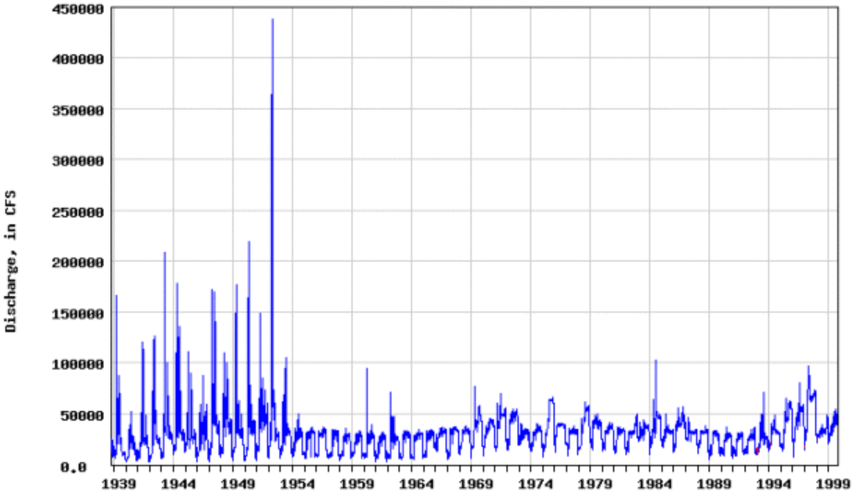

FIGURE 3.5 Missouri River discharge at Sioux City, Iowa.
SOURCE: USACE, undated.

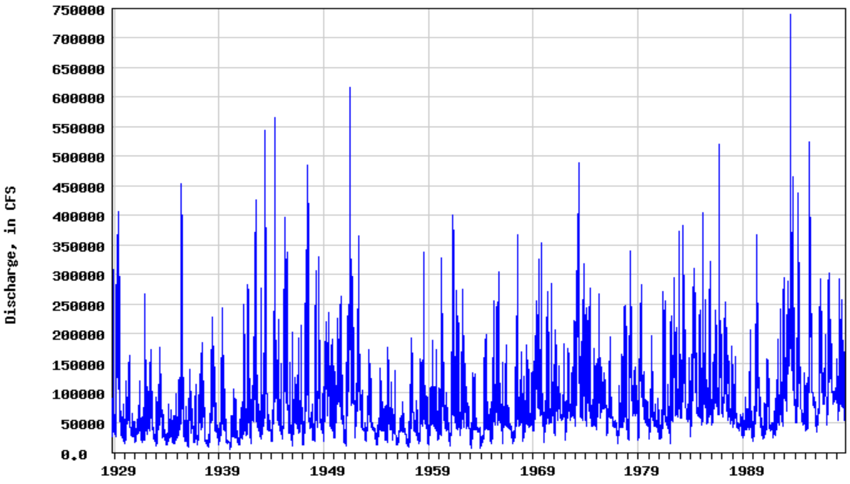

FIGURE 3.6 Missouri River discharge at Hermann, Missouri.
SOURCE: USACE, undated.

begins near Nebraska's Ponca State Park (just upstream of Sioux City, Iowa). From Ponca State Park downstream to the Big Sioux River, the river channel is stabilized. The navigation channel then begins at the mouth of the Big Sioux River at Sioux City. The navigation channel, which extends to St. Louis, ranges in width from 600 feet at the Big Sioux confluence to roughly 1,100 feet at St. Louis. Nearly all channelization activities have been conducted as part of the federal Missouri River Bank Stabilization and Navigation Project (passed as part of the 1945 Rivers and Harbors Act), which is executed by the Corps of Engineers. Channelization has been accomplished through a combination of engineering structures, including hardpoints, a variety of revetments, dikes, and sills (Slizeski et al., 1982; see Figure 3.7).

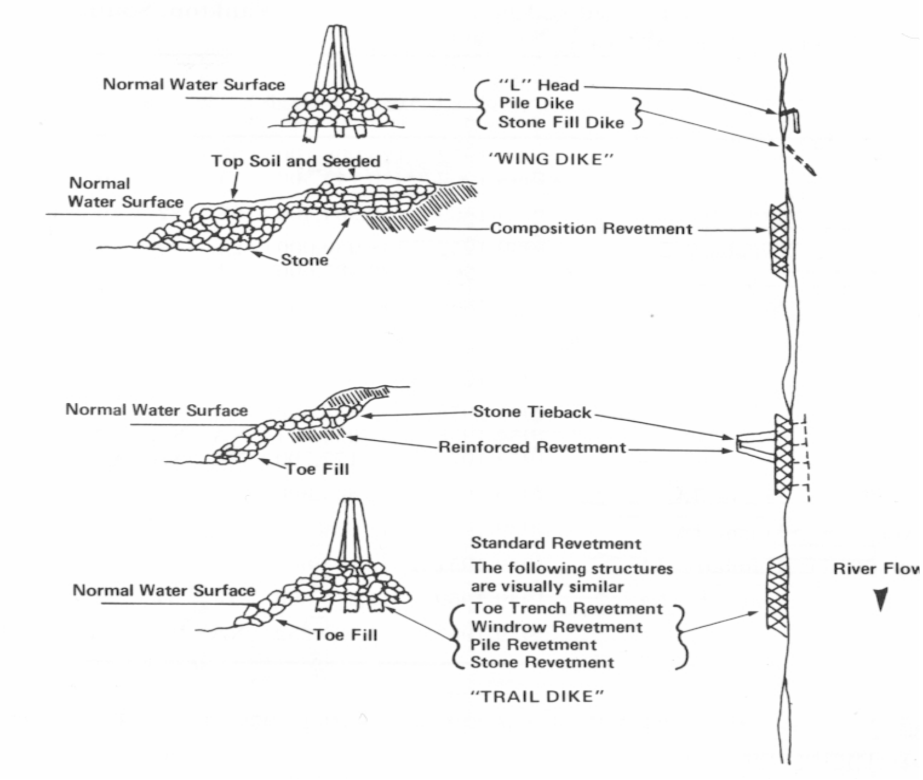

FIGURE 3.7 Commonly-used dikes and revetments along the Missouri River navigation channel.
SOURCE: Slizeski et al., 1982.

The cross-sectional shape of the Missouri's channelized portion (735 miles or about one-third of the river's length) is approximately trapezoidal. Prior to channelization, the river's flow had been swift only in its thalweg (a line connecting the deepest points of the river channel), as the river contained sloughs, sandbars, and side channels. But today the river runs swiftly throughout the entire channelized, uniform cross-section. The reduction in width, along with a decrease in flow resistance because of the uniform cross-section and the clearing of snags and sand bars, has caused an increase in flow velocity, which today measures roughly three miles per hour at usual levels of river discharge (Schneiders, 1999).

Regulation of the Missouri River's flows also changed sediment transport dynamics. Prior to regulation, the amount of sediment transported past Omaha, Nebraska ranged from 228,570,000 metric tons in 1944 to 39,909,297 metric tons in 1931. From 1940-1952 (the period from the closure of Fort Peck Dam until the closure of Gavins Point Dam), the average annual sediment load transported past Omaha was 148,930,000 metric tons. After 1954, the average sediment load was reduced to 29,487,600 metric tons (Slizeski et al., 1982).

Several inter-related processes have caused post-regulation changes in the river's rate of lateral migration. The channel downstream of the dams has degraded (deepened). Degradation occurs as a result of the water released from the dams and increased currents caused by structures that have been installed to force water into a single channel. These features downstream of dams mimic the natural tendency of flow to mobilize and transport sediment. However, once mobilized and transported downstream, there is no longer an upstream source of sediment to replace sediment removed by these flows. Replacement sediment that would have maintained the dynamic equilibrium of the channel is deposited in upstream reservoirs. But there is an abundance of sediment in floodplain areas lateral to channels below the dams that could be used to meet sediment needs in the channel.

With the exception of Oahe and Big Bend dams, where downstream reservoirs extend upstream nearly to the tailwaters of these dams, channel degradation has occurred below the dams. In the channelized section from Ponca State Park downstream to St. Louis, channel degradation occurs downstream from Sioux City, Iowa to just above the Missouri's confluence with the sediment-laden Platte River. Farther downstream, especially near the confluence of the Missouri and Mississippi rivers, the channel bed is gradually aggrading. From the confluence upstream to approximately Missouri River mile 12, Missouri River navigation channel depths are frequently impacted by Mississippi River flows, causing a backwater effect up the Missouri River that results in reduced velocities and temporary deposition (Mellema, 1986).

Channel degradation below the Missouri River's mainstem dams is well documented (Holly and Karim, 1986; Mellema and Wei, 1986; Osterkamp and Hedman, 1982; Sayre and Kennedy, 1978). For example, Figure 3.8 shows that degradation on the order of ten feet or more extends many miles downstream of Garrison Dam. Similarly, below Gavins Point Dam, the river in 1980 had degraded by 8.5 feet.

Degradation of the river channel disconnects the river channel from its floodplain. Channel degradation not only makes it more difficult for the river to overflow its banks, but it also affects the floodplain water table. Most importantly, the lack of flooding removes a source of periodic recharge water for infiltration to the groundwater table. In addition, because the water table (an alluvial aquifer) is hydrologically connected to the river channel itself, there is a consequent lowering of this aquifer in association with the lowering (incision) of the river channel. This lowering of the water table effectively drains water from oxbow lakes and wetlands. Moreover,

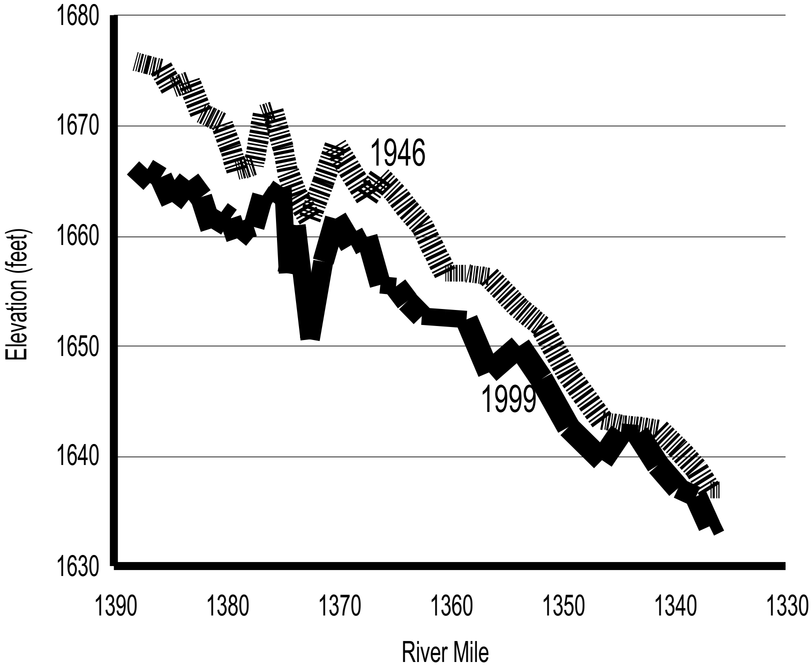

FIGURE 3.8 Average bed elevations below Garrison Dam (located at River Mile 1390) from 1946-1999 (river miles measure distance upstream from the Missouri River's mouth near St. Louis).
SOURCE: USACE 1993; 1999.

in highly-regulated stretches of the river, reduced fluctuations in river stage have resulted in reduced fluctuations in the floodplain water table. These fluctuations are important to maintaining animal and plant species richness in the floodplain, as some species will benefit from a raised water table, while other species will benefit when the water table is lower.

Channelization of the lower Missouri River and subsequent degradation of the river channel also have affected tributary streams. In upstream areas, downward incision is occurring along many of the Missouri's tributaries. This process occurs because the slope of the tributary channel bed increases in order to meet the (relatively) newly-lowered elevation of the Missouri River channel bed. Many tributaries continue to adjust to the new river bed elevation.

As channel degradation continues to entrench the stream, there are fewer overbank flows than there were prior to degradation, thus reducing interaction between the flow in the channel and floodplain. Rates of channel migration also have decreased. Lateral migration of river channels can occur in areas below dams; however, meandering rates have been markedly reduced downstream of the Missouri mainstem dams because of sharp reductions in peak flows and the armoring of streambanks. Johnson (1992) found that channel erosion and deposition rates (both indicators of river meandering rate) are only 25 percent and 1 percent of pre-dam values, respectively, downstream of Garrison Dam. Similarly, Shields et al. (2000) found that the mean rate of channel migration just downstream of Fort Peck Dam declined from 20 feet per year to 6 feet per year.

Ecological Processes

Many processes essential to maintaining ecological integrity have been altered in the post-regulation Missouri River. The spring and summer floods have been eliminated in many stretches of the river (although floods still occur in much of the river's channelized section, especially in downstream sections in the State of Missouri). The isolation of the Missouri River from its floodplain caused by river regulation structures has in many stretches largely eliminated the flood pulse and its ecological functions and services. In these areas, the absence of overbank flooding removes a source of water for the growth of vegetation, as well as a medium for fishes to move into floodplain areas to spawn and feed.

As a result of these changes, the production and the diversity of the ecosystem have both markedly declined. One of these impacts is a reduced ability for trees to regenerate. On the Missouri River and many of its tributaries, this has especially been the case for the cottonwood, largely as a result of the current low rate of river meandering (Johnson et al., 1976; Johnson, 1992). The habitat through a typical cross-section of the post-

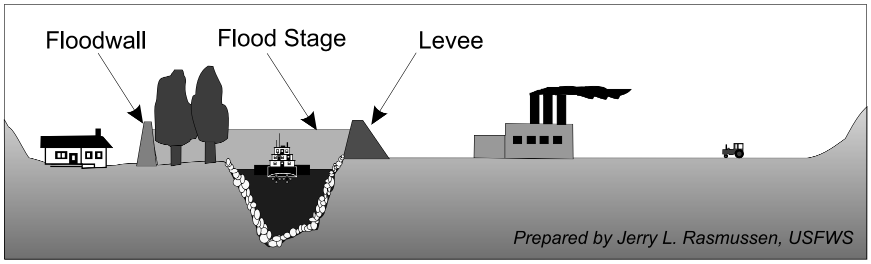

FIGURE 3.9 Typical cross-section of the post-regulation, channelized Missouri River.
SOURCE: Rasmussen, 1999.

regulation Missouri (in the non-submerged portions) has been greatly simplified (Figure 3.9). Side channels and backwater areas have been greatly reduced, thereby eliminating important habitat for many species of fishes, birds, and game. The water, sediment, and nutrients previously spread across the floodplain by overbank flows and the meandering river are now primarily restricted to the main channel or contained in the system's reservoirs. These changes, combined with other human activities in floodplain areas, have produced an ecologically impoverished ecosystem.

MISSOURI RIVER ECOSYSTEM PHYSICAL AND ECOLOGICAL UNITS

Scientific investigations today are conducted in an ecosystem that changed greatly during the twentieth century and that today is fragmented into distinct physical and ecological units. The mainstem dams, along with other flood damage reduction and navigation enhancement projects, partition the river into four sub-units that differ greatly in hydrology, sediment balance, and biota (Figure 3.10). The river can be classified into four subunits:

- Free-flowing (upstream of the reservoir system);
- Remnant floodplains (between the reservoirs);
- Channelized reach (downstream of the dams and reservoirs; the lower one-third of the river);
- Reservoirs

These categories vary markedly in the degree to which they mimic the pre-regulation Missouri River. The mainstem Missouri River is further

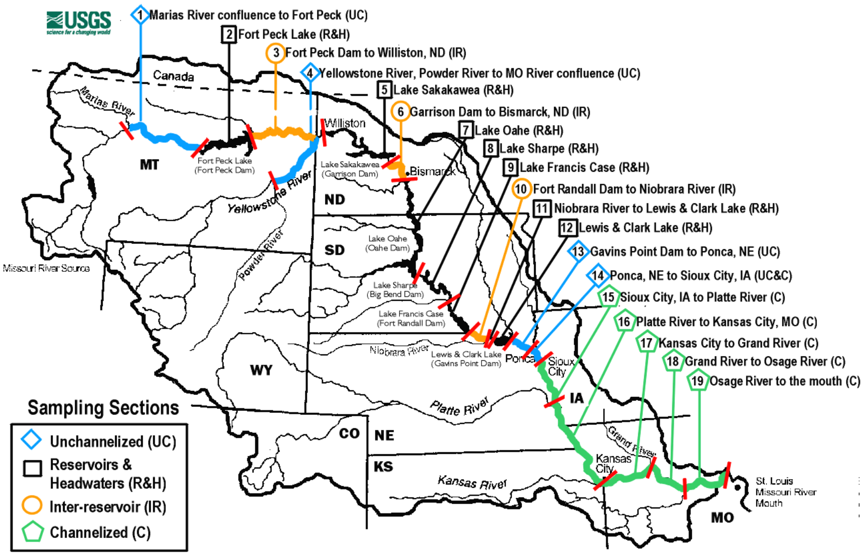

FIGURE 3.10 Missouri River basin and river reaches.
SOURCE: USGS, undated.

influenced by alterations on its tributaries. Dozens of tributaries enter the Missouri River along its course and most have experienced flow and sediment alterations by dams, water diversions, channel modifications, and land use changes to their watershed (e.g., farming and wetland drainage). The transformation of the Missouri River from a free-flowing to regulated river makes the upper basin tributaries, which are generally less regulated in comparison to lower basin tributaries, important components of a comprehensive, basinwide strategy for ecosystem restoration. Some examples are instructive.

Missouri River Tributaries

Yellowstone River

The Yellowstone River flows 675 miles through Montana to its confluence with the Missouri River at the North Dakota border (Figure 3.10). The Yellowstone River is the longest free-flowing river remaining in the contiguous United States. There are no significant impoundments on the Yellowstone's mainstem, but nearly one-third of its drainage area has been dammed and six low-head dams on the main channel divert water for irrigation (Helfrich et al., 1999). While irrigation withdrawals and tributary dams affect the river's hydrology and low-head dams restrict upstream movement of some native fishes (Helfrich et al., 1999), the river retains much of the ecological character it exhibited prior to European settlement (Jackson, 1994). At their confluence, the flow of the Yellowstone River is greater than that of the Missouri.

Where the Yellowstone River, with its abundant silt load and naturally varying hydrology, meets the Missouri River near the Montana-North Dakota border, near pre-regulation conditions exist. In fact, the Yellowstone River serves as a refuge for many of the Missouri River's native, warmwater fish (Ryckman, 2000). For example, there are high levels of paddlefish reproduction in the lower Yellowstone in years with above average streamflow. Additionally, native suckers and chubs—in decline throughout much of the river system—are fairly abundant and reproduce in the confluence area (Ryckman, 2000). Moreover, the Missouri River downstream of the confluence is a healthy riparian zone that includes ample cottonwood and willow generation maintained by floods and sediment contributed by the Yellowstone.

Bad River

The unregulated Bad River empties into the Missouri River at Fort Pierre in central South Dakota just upstream of Lake Sharpe (Figure 3.10). The Bad River is small and intermittent and therefore provides only limited ecological benefits to the Missouri River mainstem when compared to the flows of the Yellowstone River. Moreover, there is only a short distance between the confluence of the Bad and Missouri rivers and Lake Sharpe, leaving little of the sediment-deprived Missouri River downstream of Oahe Dam to benefit from the Bad River's input of sediment-laden water.

The proximity of the Bad-Missouri confluence to Lake Sharpe has caused much of the Bad River's delivery of 3.25 million tons of sediment per year to remain near its mouth, reducing channel capacity and increasing flooding in and near Fort Pierre (Thelen and Noeske, 1996). Flow releases from Oahe Reservoir (a few miles upstream of the Bad-Missouri confluence) intended to transport sediment farther into Lake Sharpe cost $12.5 million annually from foregone power revenues (Thelen and Noeske, 1993). The Bad River's high sediment transport rate results from a combination of highly erodable soils and failure to use best management practices on cropland and rangeland in the watershed (Stukel and Madsen, 2000). Better farming and ranching practices could lessen, but not stop, the sedimentation problem at the confluence and in Lake Sharpe. Thus, the condition of the Missouri River mainstem in the Pierre-Fort Pierre area depends largely on human activities in this tributary watershed.

Platte River

The Platte River enters the Missouri River near Plattsmouth, Nebraska (Figure 3.10). While the Platte's upper tributaries (South and North Platte rivers) are highly regulated and used for irrigation water, the relative lack of storage reservoirs on the Platte River itself allows considerable amounts of sediment to enter the Missouri River at the confluence. Grain sizes of this sediment range from coarse to fine sand. The sizeable increase in the Missouri River's bedload increases the potential for in-channel bar formation and alluviation on the floodplain during floods. The sediment and flow variability added to the Missouri River by the Platte River offer the potential for improving river ecology; but this potential is limited because of the Missouri River's channelized and highly regulated state both above and below its confluence with the Platte.

Kansas River

In contrast to the Bad and Yellowstone rivers, the Kansas River is heavily regulated (Figure 3.10). Eighteen reservoirs, with a total flood-control capacity of 7.4 million acre feet, have been constructed on the Kansas River (Perry, 1993). These reservoirs are intended to reduce flood damages and to enhance navigation flows on the Missouri River. Although the Kansas River is large enough to affect conditions in the Missouri River below the Kansas River's mouth, flow regulation and sediment trapping by its reservoirs reduce the potential of the Kansas River to improve ecological conditions in the Missouri River.

Physical Units of the Regulated Missouri River

Free-Flowing Reaches

The only free-flowing reach of the Missouri River lies in Montana, upstream of the mainstem dams. This reach without storage reservoirs extends from the Missouri River source near Three Forks, Montana, downstream to Canyon Ferry Reservoir, a distance of about 30 miles. However, the much longer reach from Canyon Ferry Dam to Fort Peck Lake is only mildly regulated because of the comparatively small storage capacity of Canyon Ferry Reservoir relative to total river flow and the long distance between Canyon Ferry Dam and the next downstream reservoir (Fort Peck).

Contributions from small mountain streams and springs help retain some of the natural flow and temperature patterns in this reach as well. These moderately regulated reaches have retained their essential pre-regulation characteristics, including overbank flooding, adequate sediment supply to prevent channel degradation, scattered populations of cottonwood forests similar to those observed by Lewis and Clark, and productive native fisheries (Scott et al., 1997). Floodplain vegetation in these reaches is often impacted less by river regulation than by local land use practices, such as grazing (Auble and Scott, 1998).

Remnant Floodplains

Remnant floodplain sub-units occur between reservoirs (Figure 3.10). The length of these reaches varies considerably. In some cases, the headwaters of the mainstem reservoirs extend nearly to the tailwaters of the next upstream dam; there are few remnant floodplains from Lake Oahe downstream to Fort Randall Dam. In other cases, reservoirs are separated by large stretches of river (e.g., section 3, from Fort Peck Dam downstream to Williston, North Dakota; Figure 3.10). These latter subunits have retained a natural appearance, with a sinuous channel and a wide floodplain often with oxbow lakes, sand dunes, and interspersed patches of natural forest vegetation and agricultural fields. The natural appearance, however, masks fundamentally altered hydrologic and sediment regimes. Nonetheless, many of these subunits are not physically static, and undergo natural degradation and sedimentation processes as altered by flows and releases from upstream dams and tributary inflows. Many of these segments are now incised, which has caused the loss of adjacent wetlands and secondary channels.

Streamflow through these remnant floodplain reaches depends primarily on releases from upstream dams and secondarily on local tributary inputs. Pre- and post-regulation comparisons of streamflow through these reaches can be striking. For instance, at Bismarck, North Dakota, part of which lies on the floodplain between Garrison (upstream) and Oahe (downstream) dams, the hydrograph's peak flow has been greatly reduced since the closure of Garrison Dam in 1953. Between 1928 and 1953, about two-thirds of the annual peak flows at Bismarck exceeded 2,500 cubic meters per second; since 1953, no peak has exceeded 2,500 cubic meters per second (Johnson, 1998). Reduced peak flows in the post-regulation period fail to inundate the floodplain, in sharp contrast to the Missouri River's notorious floods before river regulation. Reily and Johnson (1982) showed that Garrison Dam has also changed seasonal flow patterns; peak flows now occur in winter instead of in spring, and minimum flows now occur mainly in spring and fall instead of in winter.

The lack of overbank flooding in remnant reaches, except on the lowest terraces during extreme wet periods, has serious ecological consequences. Reiley and Johnson (1982) and Johnson (1992) reported decreased rates of both tree growth and tree population recruitment due to the absence of annual recharge of water and nutrients. Moreover, the reduced post-regulation peaks in Missouri River discharge have been insufficient to cause lateral meandering of the channel that is needed if recruitment sites for pioneer forest communities dominated by cottonwood and willow are to be created. This diverse community type is in serious decline in much of the Great Plains due to river regulation and land management (grazing) practices (Knopf et al., 1988).

Downstream effects on remnant floodplains are less severe below smaller, upstream dams. For example, Ramey et al. (1993) found that Canyon Ferry Dam and smaller dams on tributaries have decreased the magnitude of higher flows (those greater than 1,400 cubic meters per second) by 14-23 percent at Fort Benton, Montana. Downstream of Fort Benton, regeneration of cottonwood forests in constrained reaches (narrowed by high valley walls) depends entirely on such high flows (Auble and Scott, 1998; Scott et al., 1997). In this case, dams have reduced flooding at the expense of cottonwood forest regeneration and growth.

Water quality effects (most significantly cold water releases from middle levels or the bottom of reservoirs) are also most pronounced immediately below dams and diminish as one moves downstream. At the downstream end of remnant floodplains, streambed aggradation occurs where sediment carried by the river is dropped in the still water of the reservoir. Where aggradation is substantial and new vegetation curtails sediment redistribution, streamflow may be obstructed (Johnson, 2002). This causes flooding from above (overbank flow) and from below (rising water tables). This phenomenon has caused property damage near Running Water, South Dakota (upstream of Lewis and Clark Lake); Pierre, South Dakota (upstream of Lake Sharpe); and Bismarck, North Dakota (upstream of Oahe Reservoir).

Tributary streams within remnant floodplain reaches may ameliorate the effects of mainstem dams at specific locations (Johnson, 2002). Their influence depends on many factors, including the degree to which their flow has been regulated and their sediment trapped, their entry point on the mainstem (i.e., distance from mouth to nearest downstream reservoir), and their size (flow volume). Relatively natural tributaries contribute sediment and streamflow. The additional sediment and water contribute to higher peaks, turbidity, and greater flow variability, all of which are important to most native riverine organisms. Moreover, undammed tributaries often provide the shallow water and sandbar habitat for fish spawning and rearing destroyed by mainstem dams. Additionally, sediment input from tributaries can attenuate channel degradation below dams.

The most beneficial ecological effects of the Missouri River's tributary streams occur when relatively large, unregulated tributaries empty into the mainstem some distance upstream of the next reservoir. The Yellowstone River is the best example of this. There are fifteen to fifty miles of the mainstem Missouri River below the confluence, depending on the levels of Lake Sakakawea (Ryckman, 2000). The Yellowstone River adds flow and sufficient sediment to the relatively clear water released from Fort Peck Dam to cause natural cut-and-fill alluviation, riparian vegetation establishment, and successful reproduction of native fishes such as the pallid sturgeon and the paddlefish (Helfrich et al. 1999, Ryckman, 2000).

In sum, effects of reservoirs on downstream remnant floodplains are slow and progressive. These changes downstream of dams may take decades to centuries to achieve their full impacts on remnant floodplain ecosystems. However, the sediment and flow variability that tributaries contribute to some remnant reaches of the Missouri River can ameliorate some of a dam's negative impacts. In turn, this also shortens the service period of downstream reservoirs.

Channelized Reach

Downstream of Gavins Point Dam, the Missouri River has been channelized (narrowed and deepened in a relatively fixed position) from Sioux City, Iowa to its mouth to permit navigation by boats and barges, and its banks were stabilized to enhance utilization of the bankline adjacent to the channel (sections 14-19 in Figure 3.10; Schmulbach et al., 1992). In addition, chutes and side channels have been blocked and diverted, converting the once structurally-complex channels and instream islands into a single thread of deep, fast moving water. Levees have been constructed on both banks along much of the lower river to protect crops and settlements behind them; these levees constrain overbank flows to a narrow zone of the floodplain. This channelized stretch of the river was once highly dynamic:

> River surveys . . . showed that before 1930, which marked the beginning of major channel control works by the Corps of Engineers, the channel was two to three times its present width, and bars and islands existed in abundance. Floods usually brought great changes as new bars and islands were created, old ones disappeared, and the channel migrated rapidly to bring about extensive floodplain erosion and redeposition. Since 1930 and the construction of the channel control works, insular bars have appeared occasionally during low water, but their existence is only temporary; and as a consequence of channel stabilization, significant shifts of the channel even during floods have all but been eliminated (Schmudde, 1963).

The river's upper portion in South Dakota, Nebraska and Iowa has degraded because of erosive water releases from upstream dams, the trapping of sediments in mainstem reservoirs, and insufficient flows to accomplish lateral channel readjustment. By contrast, the Missouri's lower reaches (especially downstream of the Platte) have aggraded. In addition to degradation or aggradation of the channel bed, interaction (material and energy exchange) between the river and the floodplain has been significantly reduced or totally eliminated.

Engineering works on the river's main channel have resulted in significant ecological changes in the channelized reaches. Construction of revetments has greatly narrowed and deepened the channel and has fixed its location. This has virtually eliminated shallow water habitat and greatly increased water depth and current velocity. Ecological impacts of these changes on native fish and on streamside vegetation have been strongly negative (Schmulbach et al., 1992). Levees restrict the river to only a small portion of its total floodplain, except during rare floods such as in the 1990s, when some levees were breached and water and sediment moved behind the levees into floodplains (Galat et al., 1998). Overall, the levee system has reduced interaction between the river channel and its floodplain, resulting in the inability of the river to sustain its historic levels of biodiversity.

MISSOURI RIVER ECOSYSTEM SCIENCE

The Missouri River ecosystem has been the subject of scientific investigations that date back to Meriwether Lewis and William Clark and their cataloguing of Missouri River plant and animal species during their epic journey of 1804-1806. The pace of scientific investigations of the ecosystem increased notably during the second half of the twentieth century. A recent bibliography of technical reports and scientific investigations lists well over two thousand entries prior to 1997 (Burke et al., 1997). At least several hundred scientific publications have been added between 1997 and the publication date of this report.

A comprehensive review and analysis of that entire body of science was beyond this committee's means and scope. Furthermore, that research is unevenly distributed across topics; for example, there has been more scientific inquiry into select species, such as those on the federal endangered species list, than into other ecological topics such as carbon cycling or plant and animal interactions. In addressing its charge to identify the general state of that information, and to identify and prioritize key scientific questions and information, the committee thus focused its reviews on the two ecosystem components that have received the bulk of scientific attention, fisheries and floodplain vegetation.

Research on Fisheries

Ecological impacts of large mainstem dams and other human activities in the Missouri River basin were slow to be discovered. The river's biota had been at least superficially inventoried between the mid-nineteenth and twentieth centuries (e.g., Aikman, 1929; Allen, 1875; Bailey and Allum, 1962; Bennett, 1931; Fisher, 1945; Gilmore, 1911; Jordan and Meek, 1885; Linsdale, 1928; Perisho and Visher, 1912; Reid and Gannon, 1927; Stevens, 1945). However, connections between key physical processes and key ecological processes remained virtually unstudied for the Missouri River, and most large rivers, until late in the twentieth century (Hesse et al., 1989; Stanford et al., 1996). Detecting change itself during this period was difficult because the Missouri River's baseline conditions were only partially known. Moreover, when changes were documented, the causes were unclear because of the increasingly complex mix of human and natural factors affecting the river ecosystem.

Among the better-documented ecological changes on the Missouri are the development of sport and recreational fisheries in the large mainstem reservoirs, especially in the three largest reservoirs—Lake Sakakawea (Garrison Dam), Lake Oahe (Oahe Dam), and Fort Peck Lake (Fort Peck Dam). The clear water in the reservoirs provided an advantage to "sight feeding" native species, such as the walleye, which was a species in relatively low abundance whose numbers increased dramatically with habitat changes caused by the reservoirs. Just as these environmental changes made conditions better for some species, other species that were better adapted to preregulation conditions, such as the sauger, experienced declines with the replacement of a free-flowing river by the system of reservoirs. The key introduced sport species on the Missouri River is the chinook salmon. Rainbow smelt and spottail shiner have also become established and are a major food source for the salmon and the walleye. Northern pike numbers increased dramatically with construction of the reservoirs. Once the dominant sport species immediately following construction of the reservoir system, the northern pike has declined in numbers and today represents a relatively insignificant portion of the sport catch. White and black crappies responded well to the filling reservoirs and became major panfish species for a few years. The shovelnose and the pallid sturgeon are among the native species that have nearly disappeared in the reservoirs. The paddlefish has also been extirpated from much of the reservoir system, with remnant populations above Fort Peck Lake, at the confluence of the Yellowstone and Missouri rivers, and near the mouth of the Niobrara River.

Symptomatic of the changes that have occurred in the Missouri River and floodplain ecosystem are the appearance of three federally listed threatened or endangered species. These are the least tern (*Sterna antillarum*), piping plover (*Charadrius melodus*), and a unique fish species, the pallid sturgeon (*Scaphirhynchus albus*). These species have generated much attention with respect to prospective changes in Missouri River dam and reservoir operations, as the Corps of Engineers must respond to jeopardy biological opinions issued by the U.S. Fish and Wildlife Service regarding dam operations and the continued existence of these species (Appendix A, Table 4 lists the fish species found along the mainstem of the Missouri River today. The appendix also includes fishes that may exist on the floodplain in small creeks, or in overflow pools and oxbow lakes).

The Pallid Sturgeon

The pallid sturgeon was listed as endangered throughout its entire range on September 6, 1990, and the species is currently considered close to extinction (Dryer and Sandvol, 1993). Pallid sturgeons were thought to live primarily in large, turbid rivers such as the Missouri, and the Mississippi River downstream from its confluence with the Missouri. It utilized overflow areas on the floodplain, backwaters, chutes, sloughs, islands, sandbars, and main channel banklines, pools, and snags (Dryer and Sandvol, 1993). Because it feeds on aquatic invertebrates and fish that prey upon aquatic invertebrates, the lower velocity margins of the main and extra channels were essential habitats for the pallid sturgeon (Carlson et al., 1985). Some information suggested that pallid sturgeon readily utilized off-channel habitats for feeding and nursery and main channels for spawning (Dryer and Sandvol, 1993; Keenlyne, 1989; Zuerlein, 1992). Some scientists have expressed concern that pallid sturgeon cannot reproduce in the Missouri River's channelized and reservoir habitats (Henry and Ruelle, 1992; Ruelle and Henry, 1994). In 1993 it was concluded that sturgeon populations will continue to decline and that riverine habitat alteration and destruction are negatively impacting sturgeon recovery (National Paddlefish and Sturgeon Steering Committee, 1993).

Plains Minnows and Sauger

The plains minnow and the sauger are two examples of common Missouri River native fish species that declined rapidly in the aftermath of dam construction and channelization. Plains minnows were once considered the most abundant minnow in the portion of the Missouri River in upper Missouri (Cross, 1967; Fisher, 1962; Jones, 1963; Morris et al., 1972; Pflieger, 1975). This small minnow was well adapted to the river's turbid environment. It lived among the numerous sandbars, feeding on living and dead plant material, and was an important component of the trophic web of the pre-regulation Missouri River (Hesse, 1994). The plains minnow has experienced a dramatic decline in abundance and is a much smaller component of the species composition today (Figure 3.11). It rebounded for a few

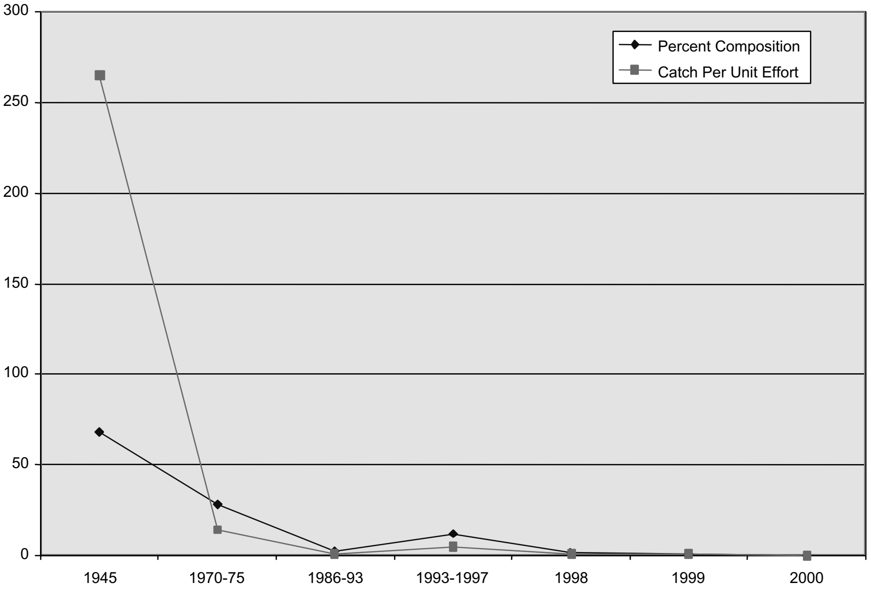

FIGURE 3.11 Percent composition and catch per unit effort of plains minnows (*Hybognathus placitus*) in seine hauls of equalized from sites adjacent to Nebraska, Iowa, and Missouri for periods between 1945 and 2000.
SOURCE: Hesse, 1994.

years during a wet period between 1993 and 1998, but the increase in abundance was quickly reversed, as floodplain connectivity was severed during 1998 and 1999.

Saugers were common prior to channelization and impoundment of the Missouri River (Cross, 1967; Jones, 1963; Jordan and Evermann, 1969). The species comprised between 10 and 65 percent of the main channel large-river fish assemblage. They have since declined by as much as 98 percent in some locations in the river (Figures 3.11 and 3.12; from Hesse, 1994). Sauger were important sport fish of exceptional food quality, and recreational anglers fished for sauger before the mainstem dams were built. They are closely related to the walleye except they were widely adapted to the turbid environment of the Missouri River, and they were much more numerous than walleye before river regulation.

The list of threatened or endangered Missouri River species continues to grow. Whitmore and Keenlyne (1990) noted that 82 species found along the Missouri River were listed as rare, threatened, or endangered by the seven states bordering the river. Included were 24 fish, 22 birds, 14 plants,

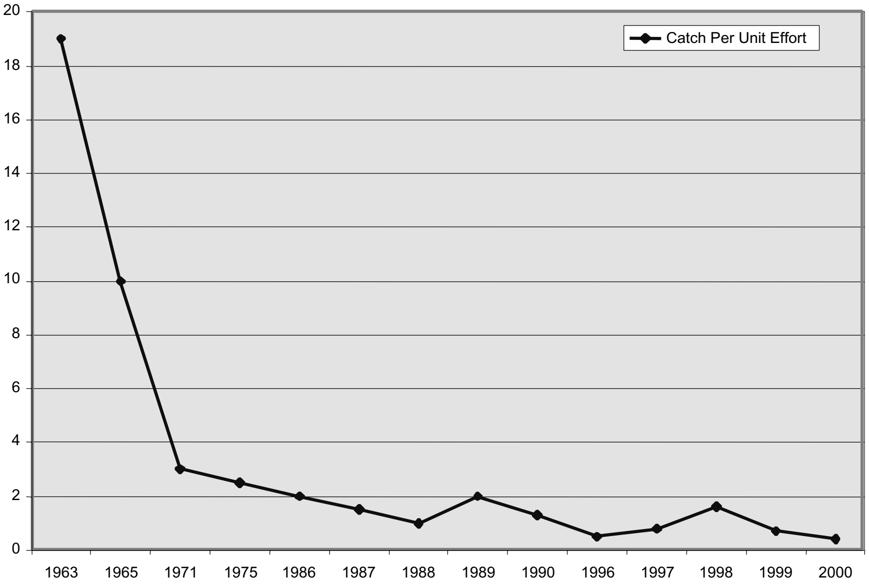

FIGURE 3.12 Catch per unit effort of sauger (*Stizostedion canadense*) by standardized electrofishing from channelized sites an the Missouri River adjacent to Nebraska and Iowa during the period of 1963 through 2000.
SOURCE: Hesse, 1994.

8 reptiles, 6 mammals, 6 insects, and 2 freshwater mussels (Appendix B lists threatened and endangered species along the Missouri River).

Research on Floodplain Vegetation

Prior to twentieth century human-induced environmental changes, the Missouri River's floodplain vegetation was a storehouse of biodiversity. One of the few comprehensive surveys of the floodplain forest flora found 220 species of vascular plants growing in the remnant river section between Garrison Dam and Oahe Reservoir in North Dakota (Keammerer et al., 1975). This inventory was conducted long after extensive forest clearing had occurred and did not include a comparably rich flora of wetland plants found in non-forest communities on the floodplain. Studies of this 75-mile floodplain remnant by Keammerer et al. (1975) and Johnson et al. (1976) revealed a mosaic of aquatic, riparian, and terrestrial communities, including oxbow lakes, ponds, marshes, sand dunes, shorelines, in-channel islands, sand bars, forests, and agricultural fields.

Natural vegetation communities along the Missouri featured forests with a wide variety of species. The dominant floodplain trees were cottonwood (*Populus deltoides*), green ash (*Fraxinus pennsylvanica var. lanceolata*), box elder (*Acer negundo*), and American elm (*Ulmus americana*). Subdominant trees included peach-leaved willow (*Salix amygdaloides*) and bur oak (*Quercus macrocarpa*). Common shrubs and woody vines included dogwood (*Cornus stolonifera*) wolfberry (*Symphoricarpos occidentalis*), poison ivy (*Rhus radicans*), chokecherry (*Prunus virginiana*), juneberry (*Amelanchier alnifolia*), woodbine (*Parthenocissus inserta*), and fox grape (*Vitis vulpina*).

Johnson et al. (1976) determined that these forests formed a successional series of ecological communities, from the youngest—dominated by cottonwood-willow formed on fresh alluvium on low benches—to the oldest—dominated by ash-box elder-elm on high benches. The river initiated the succession by meandering across its floodplain during floods and eroding older forests on the outside of river curves while creating point bars on the inside of curves for pioneer tree establishment. Approximately two-thirds of the floodplain forest flora occurred in the successional cottonwood forests that depend on river meandering.

No equally comprehensive inventories of floodplain vegetation have been published in downstream sections of the river; however, general descriptions are available and general ecological relationships are known. Downstream from North Dakota, the overall floodplain flora becomes considerably richer, particularly the woody component. For example, twenty-one species of trees were found on the Missouri River floodplain between Sioux City, Iowa and Rulo, Nebraska (Vaubel, 1973), approximately three times more than along the Missouri River in central North Dakota (Johnson et al., 1976).

On the lower portions of the Missouri River, cottonwood and willow were the dominant species on recently deposited and exposed sandbars, as they were throughout the length of the Missouri (Galat et al., 1996; Hesse et al., 1988). Later successional species were more diverse than in northern reaches of the river. For example, box elder, silver maple (*Acer saccharinum*), red mulberry (*Morus rubra*), and several elms replaced cottonwood and willow and formed an intermediate successional stage. The mature forest included several species of oaks (*Quercus* spp.), hickories (*Carya* spp.), black walnut (*Juglans nigra*), basswood (*Tilia americana*), hackberry (*Celtis* spp.), and sycamore (*Platanus occidentalis*). Weaver (1960) reported that along the Nebraska section of the Missouri River, forest, shrubs, and coarse grasses occupied most of the active floodplain, while higher terraces were nearly covered with prairie.

Much of this diverse and extensive floodplain forest was cleared before significant regulation of the river. A large portion of these woodlands was removed to provide fuel for steamboats during the nineteenth century, and more recently for agriculture. In the section of the Missouri River in North Dakota between Garrison Dam and Oahe Reservoir, 38 percent of the floodplain forest was cleared for agriculture between 1881-1938, an average rate of approximately 0.7 percent per year (Johnson et al., 1982). An additional 18 percent of the forest was cleared for cultivation between 1938-1979, an average rate of approximately 0.5 percent per year. The majority of the woodlands along the river were removed to provide fuel for steam-powered vessels during the nineteenth century, and more recently for agricultural purposes. Thus, clearing activities claimed approximately 56 percent of the original floodplain forest by 1979. Considerably more forest has been cleared since then, but the amount has not been quantified.

Clearing of the Missouri's floodplain forest occurred much earlier along the river's lower portions. Bragg and Tatschl (1977) estimated that 76 percent of the floodplain in Missouri was forested in 1826. By 1937, the percentage had dwindled to 17 percent, and by 1972 had dropped to 13 percent. The percentage of the floodplain cultivated increased accordingly, from 18 percent in 1826 to 83 percent in 1972.

Hesse et al. (1988) estimated cover changes on the floodplain for a larger area, from St. Louis upstream to Rulo, Nebraska, including the area studied by Bragg and Tatschl in 1977. Cultivated land increased 43-fold between 1892 and 1982 (from 2,339 hectares to 100,091 hectares), while during the same period forests decreased by 41 percent, wetlands by 39 percent, sandbars by 97 percent, and grasslands by 12 percent (Hesse et al., 1988). The authors suggested that higher floodplain ground was cleared of forest prior to the dams. Dam construction and the cessation of flooding then stimulated another round of forest conversion to agriculture downstream of and between the reservoirs, this time on lower ground.

Significant changes in Missouri River fauna also occurred long before river regulation. For example, some of the nearly 160 species and their habitats first described by Lewis and Clark (Burroughs, 1961) went extinct or were extirpated from the region because of hunting and loss of habitat. These species included bison, elk, grizzly bear, wild sheep, swans, and the Carolina parakeet. These animals used the Missouri River valley as protection from harsh winters and summer heat. The beaver was essentially trapped out of much of the northern Great Plains. Wetland drainage, stream channelization, and trapping kept beaver numbers low during much of the first half of the 1900s (Bennitt and Nagel, 1937). More recently, due partly to the declining value of wild fur, beaver are more numerous even along portions of the channelized reaches (Larry Hesse, River Ecosystems, Inc., personal communication, 2001).

Botanical research from 1960 to 2000 on the upper Missouri River centered on the effect of dams on floodplain forest succession, particularly the effect of altered hydrology and sediment regime on river meandering and on cottonwood regeneration. Natural succession patterns were worked out in remnant reaches shortly after the dams were built. No comprehensive studies of forest succession were conducted prior to construction of the mainstem dams. Botanical research was concentrated in two Missouri River reaches—the unchannelized floodplain downstream from Gavins Point dam (Wilson, 1970), and the remnant floodplain between Garrison Dam and the headwaters of Oahe reservoir, near Bismarck, North Dakota (Johnson et al., 1976). Later investigations of cottonwood regeneration in the reach of the Missouri River's section designated as a national monument in Montana (formerly designated Wild and Scenic) were conducted by Scott et al. (1997) and others.

The studies in North Dakota reconstructed (post hoc) the patterns and processes of forest succession on the Missouri River floodplain under natural, pre-regulation conditions, concluding that the key geomorphic process directing vegetation succession was the river's meandering channel. The Missouri River moved across its floodplain during high flow periods; its rate of movement was especially rapid during floods. In places, the river had moved several miles in less than a century (Johnson, 1992). During episodes of meandering, the outer bank of the river eroded while the inner bank accreted. On the river's outer curve, forests in various stages of successional development, along with other floodplain habitats such as sand dunes and marshes, were undermined. On the river's inner curve, new land formed that was ideal for forest regeneration. During floods, the Missouri River channel was filled with fallen trees, which eventually settled to the bottom of the river and became snags. Cottonwood and willow (both tree and shrub growth forms) were the first woody species to colonize the newly accreted areas (point bars). They dominated the pioneer vegetation throughout the length of the Missouri River, but were especially important in the upper, more westerly, reaches where few other tree species could grow.

The success of cottonwood and willow was attributed to their specific adaptations to riparian zones, which includes: rapid seed germination to grow immediately after spring floods, rapid root and height growth enabling tolerance to flooding, drought, and sedimentation, tolerance to the often low soil fertility on sandbars, and the ability to reproduce vegetatively, particularly after physical damage from floods or from beaver. Evidence for the success of cottonwood was its historic dominance of the floodplain vegetation; over eighty percent of the extensive forests on the floodplain of the pre-regulation Missouri River in North Dakota had cottonwood as their most important tree (Johnson et al., 1992).

Research also uncovered a key fact about cottonwood: It cannot reproduce successfully in its own forests. As such, it depended on the creation of new land from an actively meandering river for its persistence and prominence in the vegetation. It behaved as a disturbance-dependent, fugitive species that declined in abundance in stable portions of the floodplain while increasing in other portions recently reworked by the Missouri River. Later successional tree species replaced it over time in stable areas.

The Missouri River's pre-regulation floodplain was a mosaic of forests with a wide range of ages, from young cottonwood-willow forests a decade or two old, to forests of ash, box elder, elm, and oak that were old enough to have lost all traces of the cottonwood pioneer element. Of the forests studied by Johnson et al. (1976), approximately two-thirds were early to mid-successional (dominated by cottonwood), while one-third were dominated by later successional tree species.

High biodiversity both within forest communities and across the floodplain could not be maintained without the rejuvenating forces of floods and channel meandering. Johnson et al. (1976) found the highest tree diversity mid-way through succession, a period when all tree species grew together, with cottonwood and willow in the overstory, and with ash, box elder, elm, and oak in the understory. Hibbard (1972) found similar patterns for forest-dwelling animals; the number of species of both small mammals and birds peaked in forests of mid-successional age. This ephemeral, species-rich stage was historically sustained by new forests created by a meandering river.

Hibbard (1972) found that the floodplain forest community provided nesting habitat for a wide range of bird species, from open country birds in the youngest, post-flood communities, to shrub-loving bird species in middle-aged cottonwood communities, to forest-dwelling birds in the most mature forests. Peaks in both species number and population of birds were reached in older successional forests because of their high vertical stratification (Hibbard, 1972). The large size and hollow trunks and branches of older cottonwood trees provided nesting cavities for woodpeckers and wrens (Knopf, 1986). More than 50 species of songbirds were found by Liknes et al. (1994) along the upper Missouri River, and approximately 50 percent were neotropical migrants. Dean (1998) found 39 species of neotropical migrants utilizing Missouri River floodplain forests as stopover habitat.

Model calculations suggest that without changes to the current management regime, cottonwood forests will essentially be lost as a significant community on remnant floodplains in less than a century (Johnson, 1992). The cottonwood forests that remain on the floodplain between and immediately below dams cannot be sustained by the current low river meandering rates. Both erosion and deposition rates (an index of river meandering rate) have decreased substantially since the closure of the mainstream dams. Deposition rates have fallen to one percent of their pre-regulation levels and erosion rates have fallen to twenty-five percent of their pre-regulation levels. Cottonwood forests are forecast to be replaced by those dominated by green ash. These future forests, assuming that they escape clearing for agricultural expansion, are likely to be considerably lower in tree and bird diversity primarily because of the loss of pioneer plant species, loss of vertical structural complexity, and the loss of nesting cavities found mostly in old cottonwood trees.

Reduced channel meandering was not the only impact of flow regulation by dams on floodplain vegetation. Reily and Johnson (1982) found that seasonal shifts in flow, the near-elimination of overbank flooding, and a lowering of the water table below the floodplain in late spring, reduced the growth of trees occupying remnant floodplains between reservoirs. Peak river flow no longer occurs early in the growing season. It is consequently out of phase with the vernal growth pattern typical of floodplain trees. The absence of flooding except on the lowest benches represents a loss of soil moisture to the floodplain compared to pre-regulation conditions. Climatic conditions in the upper Missouri River region are relatively dry. As such, overbank flooding was important for the growth and persistence of trees.

Several scientists have recommended measures to regenerate cottonwood forests in sections of the Missouri River affected by mainstem dams. Johnson (1992), for example, suggested planting native pioneer trees, such as cottonwoods and willows, on marginal agricultural land unless a more natural flow regime could be restored. While planting can, with time, maintain certain important ecosystem properties, such as cavity-nesting habitat for birds, it cannot restore certain other properties, such as the high species diversity of early successional forests. Pre-regulation forests were established on relatively low benches and were repeatedly aggraded by siltation from floods. As a result, these communities supported a significant proportion of wetland species. This species diversity cannot be restored by tree planting on relatively high benches.

COMMITTEE COMMENTARY

The Missouri River ecosystem experienced a variety of human-caused environmental changes during the twentieth century. Before these changes, the Missouri River experienced annual floods, with occasional massive flooding. It meandered freely across its floodplain, it carried large amounts of debris and snags, especially during floods, and it eroded, transported, and deposited voluminous amounts of sediment. These dynamic geomorphic processes promoted erosion on the river's undercutting banks and deposition on its inner banks. This pre-regulation, physical variability was important to sustaining the river system's biological diversity and production.

Engineering works constructed during the twentieth century aimed to enhance conditions for navigation and to provide protection against floods by reducing this variability. Mainstem dams and channelization greatly changed the river's physical systems. Much of the river's huge sediment load was deposited in the massive reservoirs, resulting in sediment imbalances and marked channel incision below the dams. The massive mainstem reservoirs submerged stretches of free-flowing river and floodplain forest. Changes in habitat allowed some native species that were challenged by pre-regulation conditions to thrive. Some species that thrived under pre-regulation conditions, such as the pallid sturgeon and sauger, experienced sharp reductions. The river's periodic flooding also was greatly reduced, and even eliminated, in stretches under the dams' stabilizing influences. This resulted in the reduction or loss of ecologically-beneficial flood pulses and low flows. The hydrologic connections between the river channel, floodplain, and backwater areas were greatly disrupted. In the channelized portions, river meandering was eliminated and the ecological diversity of the river and floodplain was greatly simplified.

A large body of scientific research has identified these ecological changes, including declines in many native species and a general decline in the overall integrity of the ecosystem that have accompanied the mainstem dams and other human influences on the ecosystem. As in all large ecosystems, uncertainties—some of which are essentially irreducible—remain in the scientific understanding of the Missouri River and floodplain ecosystem. Nonetheless, the scientific research provides a good picture of the fundamentals of the ecosystem's pre- and post-regulation ecological structure and function.

Although much contemporary research retains a species-specific focus, some scientists and organizations are integrating research across disciplines and across the entire river system. This broader perspective and inquiry will complement the existing science in promoting a more systematic understanding of the Missouri River ecosystem.

Mainstem dams and reservoirs, channelization, and a management regime that promotes hydrologic stability have all contributed to reductions in the ecosystem's dynamic properties. Current scientific inquiry is thus hindered in its ability to investigate these dynamic processes and how they affect the ecosystem and its cadre of organisms. The greatest unknowns in the science of this ecosystem are in understanding its responses to changes in the current management regime.

4

Values of the Missouri River System and Operations

> *The principal possible source of conflict of navigation and other water uses is with irrigation requirements. The probability of such conflicts within the next 30 years is not high. Beyond that period the possibility of conflict is minimized by measures which could be taken to reduce water flow requirements for navigation . . . It is therefore concluded on the basis of available data that navigation does not appear to be physically incompatible with other water uses on the Missouri.*
>
> The President's Water Resources Policy Commission, 1950

In large and highly-controlled river systems like the Missouri, comprehensive and accurate knowledge of system values can be useful in making decisions about reservoir release schedules. This knowledge is particularly important in systems in which adjustments to dam and reservoir operations are being contemplated. Such changes will entail tradeoffs between different uses and values. An understanding of the economic and ecologic effects of these tradeoffs requires knowledge of methods for measuring values, from standard quantification of flood-damage reduction benefits to more novel quantification of ecosystem services. Of particular relevance in this report are those values associated with operations of the mainstem reservoir system and the links between operations, ecology, and social values. Values involved include those of hydropower distributors and users in the upper basin, floodplain farmers and other property owners, water users from Fort Peck Dam downstream to St. Louis, shippers on the channelized portions of the Missouri River, water-based recreation users, and other outdoor recreation users who currently are or potentially would be using the Missouri River ecosystem for fishing, birdwatching, hunting, and other leisure activities.

ECONOMIC AND SOCIAL FEATURES IN THE MISSOURI BASIN

Economic activities in the Missouri basin can be divided between those in the upper and those in the lower basin. Most of the population and wealth are concentrated in the lower basin. For example, St. Charles County, Missouri, which is part of the St. Louis metropolitan area, has a population of 250,000 and has a total personal income of over $6 billion (1997 dollars). By contrast, Williams County in northwestern North Dakota (Williston) has a total personal income of $400 million and a population of 20,000. Aside from service activities, oil and gas extraction is the largest source of income in Williams County. In 1997, farming in Williams County showed a loss of $7 million, while in St. Charles County, farming earned $7 million (U.S. Department of Commerce, Bureau of Economic Analysis, Jan. 2000, http://www.doc.gov). Per capita income in Williams County was about 20 percent less than it was in St. Charles County, and it was generally at lower levels in the rural counties throughout the basin. Where counties are largely occupied by Indian reservations, per capita personal income is even lower, dropping to $11,783 in Dunn County, North Dakota, and to $15,831 in Mountrail County, North Dakota, the home counties of the Fort Berthold tribes. Many of these Indian reservations are in the upper basin.

Important commercial centers along the lower Missouri River are Sioux City, Omaha, Kansas City, St. Joseph, and Jefferson City. Important commercial centers on the upper river are Great Falls, Williston, Bismarck, Pierre, and Yankton. Economic activities of the Missouri basin's commercial centers are no longer tied directly to the Missouri River. These cities, settled because of river navigation, initially flourished because of early commercial successes in processing, manufacturing, and distribution, later flourishing as transportation hubs for railroads and highways. These economies are today based largely upon services, wholesale-retail activities, and government activities. Manufacturing and transportation together make up about a quarter of these economies. Although not specifically identified in government statistics, river- and water-related tourism and recreation are components of the service sector in parts of the basin, especially the upper basin.

The most striking demographic feature of the basin is the twentieth-century exodus from rural to urban areas. Populations are declining in much of the region, in some cases dramatically. During the 1990s, eastern Montana, for example, experienced a net population loss. Small net population gains in the Dakotas mask the fact that nearly all the population growth has been in the states' cities; most rural areas are experiencing population declines. Many areas in the upper basin are populated by fewer than six people per square mile. North Dakota's and South Dakota's

1990-2000 population gains were among the smaller in the nation and eastern Montana experienced a net population loss. Population densities decrease as one moves upstream along the Missouri River. Montana, North and South Dakota, and Wyoming are the four least densely populated states in the contiguous United States. North Dakota's population growth of 0.5 percent in the 1990s was the lowest of any U.S. state (http://www.census.gov).

Economic fortunes within the basin mirror its varied demography. The contrast between the upper and lower basin is illustrated by the fact that the economy of the Kansas City area alone is greater than the combined economies of the two Dakotas and Montana. The economy of the Omaha area—which is about 40 percent the size of the Kansas City economy—is larger than the state economies of the Dakotas or Montana.

ECONOMIC OUTCOMES OF PICK–SLOAN

During construction of the Pick–Sloan project, it was expected that multiple-purpose water projects would stimulate regional economic and population growth and produce national benefits in excess of their costs. Since Pick–Sloan construction, however, society's faith in large water projects to produce vast benefits has waned. That the Pick–Sloan Plan has yielded benefits has long been clear, but today the social costs of Pick–Sloan are better understood. As the World Commission on Dams observed, "Dams have made an important contribution to human development, and the benefits derived from them have been considerable" (WCD, 2000). But the commission also noted "in too many cases an unacceptable and often unnecessary price has been paid to secure those benefits" (ibid.).

Projected water project costs and benefits are calculated through formal benefit–cost analysis. The U.S. Army Corps of Engineers has been charged with calculating these costs since the 1936 Flood Control Act. Benefit–cost analysis has evolved from calculating the more obvious costs and benefits of dams and large water projects, to more subtle calculations, such as the benefits of outdoor recreation and the flows of ecosystem benefits produced by aquatic ecosystem restoration. Benefit–cost analysis has a history of classifying difficult-to-measure benefits and costs as "intangible," "noneconomic," or "immeasurable." However, this practice may not have promoted sound decisions, because things beyond the boundary of quantification tend to be ignored or undervalued. Fortunately, methods and procedures for quantifying the difficult to quantify are becoming more easily available (U.S. WRC, 1983; NOAA Panel on Contingent Valuation, 1993, p. 4601–4614; Daily et al., 2000).

Project Outputs and Benefits

Benefits from the Pick–Sloan Plan are measured in monetary units. The Corps of Engineers currently measures benefits from the Pick–Sloan projects for the Master Manual Study according to criteria and methods prescribed in the *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (Principles and Guidelines,* or simply *P&G*; U.S. WRC, 1983). System outputs assessed in Corps reports are power, navigation, flood damage reduction, water supply, and recreation. The *P&G* defines benefits as net additions to the national income, or National Economic Development (NED). The following sections describe the products of the Pick–Sloan Plan, including the dollar value of benefits (and costs in the case of navigation) and the distribution of benefits among states or among particular uses in the case of water supplies.

The values listed in this chapter were obtained from Corps of Engineers studies published in 1994 and 1998, as cited. Most benefit estimates represent snapshots of normal or average years of operation. The numbers do not involve trends but rather reflect levels of use, or in the case of flood-damage reduction benefits, levels of floodplain occupancy at the time of the studies. The observations on distribution of benefits among the states are from regional studies conducted by the Corps' Institute for Water Resources in Alexandria, Virginia. The purpose of examining benefits (and costs, where appropriate) is to better understand the relative importance, in commensurable terms, of the various quantified outputs from the Missouri River system. This committee was not requested to conduct a comprehensive ex post economic analysis of Missouri River mainstem dam and reservoir operations, and therefore has not attempted to produce a detailed comparison of total benefits and costs for the project. Only in the case of navigation are costs discussed, and that is because the Corps has been able to identify specific engineering costs of maintaining the navigation channel. When "benefits" are discussed, these are gross benefits before any costs are subtracted. If any costs are subtracted, the term "net benefits" is used to reflect this.

For purposes of comparison, the major benefits of Pick–Sloan come from hydropower, water supply, and flood-damage reduction, each of which has annual benefits measured in hundreds of millions of dollars. Recreation comes next, with annual benefits measured in the tens of millions of dollars. Navigation follows, with annual benefits measured in millions of dollars. The benefits of ecosystem services that have been foregone in order to achieve other benefits have been measured only in a 1981 study, which projected a loss of nearly one million recreation-based days of hunting, fishing, sightseeing, and boating annually in the current Missouri River dam operating plan (USACE, 1981).

Observable differences in the distribution of benefits within the Missouri basin can be summarized as follows. Missouri has the biggest share of flood-control and navigation benefits. Nebraska has the largest share of water supply benefits. North Dakota and South Dakota realize most of the recreation benefits. Irrigation benefits (included in water supply benefits) are only about one percent of all benefits. That there may be different interests expressed by the states based on such asymmetric distribution of benefits comes as no surprise to observers of current events in the Missouri basin.

Navigation

The most controversial benefit calculation in the Missouri River dam and reservoir system is the value of lower basin navigation enhancement activities. This issue dates back to the first decade following passage of the Pick–Sloan Plan. Writing in 1965, a Stanford University political scientist reported that the 1953 Missouri River Basin Survey Commission "in reviewing the Corps' navigation program on the Missouri could only find one-twelfth of benefits from erosion control and one-third of the savings to shippers claimed by the Corps. The Commission's benefit-cost ratio was half that calculated by the Corps" (Marshall, 1966). Figure 4.1 shows the tonnage carried by navigation on the Missouri from 1960 until the present. In discussing navigation traffic on the Missouri, it is necessary to separate commercial traffic (e.g., corn, soybeans, fertilizers) from the movement of sand and gravel from commercial mining operations, and from the movement of waterway materials connected with construction and maintenance of the navigation channel. Commercial traffic peaked in 1977 at 3.3 million tons or 1.5 billion ton-miles. By 1997, it had dropped to 1.6 million tons or 0.7 billion ton-miles, a fairly steady decline interrupted only by recession or drought years and subsequent recoveries (USACE, 2000a). By the 1990s, commercial traffic had leveled off to an average of 1.5 million tons (0.65 billion ton-miles).

Commercial traffic levels on the Missouri have fallen short of the Corps' 1950 projections. The shortfall has been largely because of agricultural grain, food, and food product tonnage failing to meet expectations. After peaking in the 1970s, agricultural tonnage has been in steady decline. The reasons include the development of low-cost unit train traffic to high capacity ports in the Pacific Northwest, the decline in agricultural exports in the 1980s, and the growth of local consumption of products for feed and processing. The drought of the late 1980s and early 1990s also depressed agricultural traffic (USACE, 2000b). Baumel (1998) noted that down-

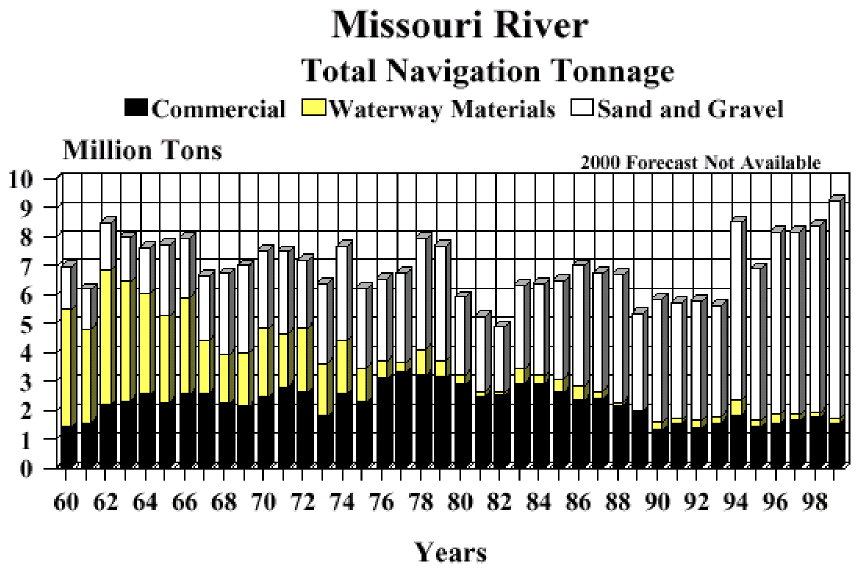

FIGURE 4.1 Total tonnage transported on the Missouri River, 1960–1999. SOURCE: USACE, 2000a.

stream corn and soybean shipments are "back hauls" that take advantage of empty barges that have transported fertilizer upstream. Without the empty barges already being upriver, corn and soybean shipments would not be economically viable (Baumel, 1998). In 1998, fertilizer, other chemicals, and primary manufacturing goods comprised 42.8 percent of commercial tonnage while agricultural products comprised 40.6 percent of commercial tonnage (USACE, 2000a). The Missouri River basin is in an unfavorable competitive position for reaching export markets compared to other regions. Because in the United States, waterborne agricultural shipments primarily serve export markets, this unfavorable competitive position "likely will continue to constrain Missouri River navigation tonnage" (USACE, 2000b).

Sand and gravel mining, largely unanticipated in the earlier projections at 6.5 million tons of traffic in 1998, now accounts for over 70 percent of total tonnage (USACE, 2000a). This traffic involves hauls of one to three miles from the dredge to onshore storage sites. Sand and gravel traffic, together with the haulage of waterway materials in connection with the construction and maintenance of the navigation channel, currently account for nearly 80 percent of total waterway tonnage. Because of sand and gravel traffic, total tonnage on the Missouri has exceeded the 1950 projection by 100 percent (USACE, 2000b). Nonetheless, sand and gravel traffic peaked at 4 million tons in 1981, declined in the next recession, peaked again in 1990, declined in an ensuing recession, and then rose to a new high in 1998. If construction continues to grow in the river corridor, sand and gravel traffic should grow apace.

Navigation benefits reported by the Corps for 1994 were $6.3 million from 1.8 million tons of commercial traffic, and another $1.7 million from the movement of 6.7 million tons of commercial sand, gravel, and waterway maintenance materials (USACE, 1998a). In 1994, passenger cruise ship benefits were $0.7 million based on a value of $6.08 per user for a cruise that runs from St. Louis to Kansas City. These figures are based on 1994 traffic and 1995 price levels (USACE, 1998a).

Net Benefits of Commercial Navigation

Commercial navigation traffic had total benefits of $7.0 million in 1995 (USACE, 1998a). This figure can be compared with annual operation and maintenance costs for the navigation channel that the Corps is able to estimate because of the specificity of navigation maintenance costs. The Corps has projected its navigation benefits and its operations and maintenance costs at a range of flows or “service levels.” The Corps has found that at full-service levels of Missouri River flow of 35,000 cubic feet per second (cfs), there are net benefits of less than $3 million annually from commercial traffic (USACE, 1998a). This estimate appropriately excludes traffic in sand, gravel, and waterway materials, but may inappropriately ignore recreational boating benefits that may or may not depend upon a fully maintained navigation channel. As flows fall below 35,000 cfs, net benefits of commercial navigation fall off rapidly, reaching 0 at around 30,000 cfs (USACE, 1998a).

Navigation benefits are measured as the value of savings in transportation costs. As required by law, shipping rates are used as the basis for calculation (P.L. 89-670). Ideally, long-run marginal costs of the alternative mode of shipping would be employed as the basis for calculations. The *Principles and Guidelines* observes that shipping rates may not be the best approximation of long-run marginal costs (U.S. WRC, 1983). A National Research Council committee that reviewed the Corps’ draft feasibility study for the Upper Mississippi River–Illinois Waterway concluded that the Corps needs a better data base of the price, origin, and destination of freight shipments by barge and alternative modes (NRC, 2001).

The definition of navigation benefits is a major issue in any discussions of modifying Missouri River dam and reservoir operations. This committee noted that as net navigation benefits are sufficiently small in total and that as traffic volumes decrease as one moves upstream, an incremental analysis of the economics of retaining segments of the navigable waterway would appear to be useful. This would especially be the case if relaxing the duty to maintain navigation flows in an upstream segment made it demonstrably easier to introduce restoration flows in that segment. As an example, if the segment from Omaha to Sioux City proved to be uneconomic in comparing its incremental benefits with its incremental costs, then that segment would be a prime candidate for efforts at restoring some ecological benefits through operational changes that would compromise, but not necessarily eliminate, navigational uses. The effects of dam releases are mostly abated by the time the river passes Nebraska City, Nebraska, located near the Iowa-Missouri border about 150 miles downstream of Gavins Point Dam (Hesse, 1994). Thus, even if navigation were significantly reduced on the stretch between Sioux City, Iowa and Nebraska City, and there were subsequent changes in flows out of Gavins Point Dam, there would be negligible hydrologic effects on Missouri River navigation downstream of Omaha.

The next segment to be examined in sequence would be from Omaha downstream to some point below Omaha. In proceeding segment by segment, the analysis should discover a point at which it is beneficial to retain navigation to the mouth of the river.

Water Supply Benefits

Water supply benefits accrue at intakes for thermal power plants and at municipal, irrigation, commercial/industrial, domestic, and public water intakes so long as daily flows exceed minimum elevation requirements for the water intakes. The operating plan assures that daily flows will exceed the minimum elevation as much of the time as is feasible. The greatest numbers of intakes are above Gavins Point Dam for all types of use except power plants. Of 25 power plants using river water, 18 were below Gavins Point and accounted for 73 percent of total generating capacity. By far the largest numbers of intakes overall were for irrigation (891) and domestic (579) supplies. There were 57 municipal intakes serving 3.1 million people. Of these, 2.9 million persons are served below Gavins Point by 19 supply intakes (USACE, 1994a).

The benefits of water supplies are evaluated by the alternative-cost method, the cost of the next best alternative supply facing each user. The next best alternative is required to be a likely alternative that incorporates reasonable nonstructural and conservation measures. In 1994, the Corps found \$571.6 million in annual benefits—essentially savings in cost—from the withdrawal of water from the Missouri River mainstem, starting at Fort Peck Lake and proceeding downstream (USACE, 1994a).

Water supply benefits are concentrated in the thermal generating activities in Nebraska and Iowa. Of the total benefits, 91.4 percent accrue to power and 5.6 percent to municipal water supplies. Irrigation gets 2.3 percent, mostly in South Dakota. Of the total water supply benefits of $541 million, Nebraska receives 44.8 percent, Iowa 16.4 percent, and Missouri 15.9 percent (USACE, 1998a).

In its Master Manual studies, the Corps was concerned with the effects on water user costs of lower levels of the river than are achieved by normal operations. Cost functions relating withdrawals to river levels are relevant for computing benefits (changes in user costs) of different operating plans. All the options examined in its Draft Environmental Impact Statement indicate lowered benefits (increased costs) to water users.

Minimum daily flows also help to meet water-quality objectives in the channel, although the mainstem reservoirs seem to present the most frequent water-quality problems. Lake Sakakawea has experienced algal blooms, and other mainstem reservoirs have exceeded state or U.S. Environmental Protection Agency ambient water-quality in the reservoir or in

Box 4.1
Irrigated Agriculture

The upper Missouri River basin states expected to gain substantial irrigation benefits from the Pick–Sloan Plan, but these benefits never materialized. Irrigation accounts for a little over $12 million in water supply benefits. These are cost savings to the 891 private irrigators who have permits to withdraw water from the Missouri River mainstem or reservoirs under Corps jurisdiction. There were two mainstem federal reclamation projects authorized in Pick–Sloan, the Garrison Project in North Dakota and the Oahe Project in South Dakota. The Garrison Diversion Unit included McClusky Canal, Jamestown Dam and Reservoir, and Garrison Dam and Reservoir.

Reservoirs have been constructed along with some of the canal system but the only irrigation is limited to a small test area near Oakes, North Dakota. Lake Oahe was to provide water for the Oahe Unit. Most of the delivery features have not been constructed and no water is delivered from Lake Oahe. James Diversion Dam is the only feature that has been completed (Carrels, 1999).

Of 4.7 million acres of “full service” irrigation projected in the Pick–Sloan Plan, 465,000 acres have been developed under the Bureau of Reclamation (U.S. Department of the Interior, 1989). These developed acres are found on tributaries primarily in Nebraska, South Dakota, Wyoming and Kansas and are not included in the committee’s discussion of mainstem benefits. Some private projects also receive Pick–Sloan water. In a 1958 formulation of project benefits by the Corps, the primary plus secondary irrigation benefits allocated to the mainstem reservoirs were projected to be $9.8 million annually, or about 9.5 percent of the total benefits estimated for flood-control, navigation, power, and irrigation (USACE, 1958). Today’s irrigation benefits from 891 private intakes along the mainstem are about 1 percent of aggregate benefits and were not accounted for in original plans.

reservoir outflow for a variety of constituents like iron, manganese, agricultural chemicals, and arsenic (USACE, 2000a). Minimum daily flows are also important for meeting ambient water temperature standards below the thermal-electric power plants.

Recreation

Although they did not represent prominent benefits when the Pick–Sloan projects were constructed, water-based recreational uses and benefits have grown substantially along the Missouri River, especially in the upper basin. Figure 4.2 shows that recreation on the reservoir increased from 5 million visitor hours each year in the mid-1950s to over 60 million visitor hours in 1998–2001. Except for setbacks in periods of drought or recession, the annual growth of visitor hours on the reservoir has been remarkably steady. A slackening in the trend is not yet apparent, although there may be different trends in different reservoirs. Visitation has leveled off since 1997. No annual statistics are systematically compiled for recreation in the mainstem channel.

Based on methods described in the *Principles and Guidelines*, annual recreational benefits in 1994 were estimated at $87.1 million (USACE, 1994b). This is for the entire system starting with Fort Peck Lake and proceeding through the lower river. The benefits are willingness to pay values for water-based recreation that includes fishing, boating, picnicking, and water sports. Recreation-related benefits were generated from different parts of the system as follows: the upper lakes and open reaches down through Lake Oahe accounted for 47.2 percent of the benefits; the lower lakes including Lake Sharpe (Big Bend Dam) and Lewis and Clark Lake (Gavins Point Dam) accounted for 30.9 percent of the total; and the lower river below Gavins Point Dam (essentially the navigable portion of the river) accounted for 21.9 percent of the total, or $19 million. The Corps' own studies of visitor use were supplemented with surveys by the states. The system as a whole yielded 10.2 million recreation days annually from 1992 and 1993 studies. Visitor use at mainstem reservoirs has increased somewhat since these studies were made, but estimates of benefits have not been updated. Because it is concerned with estimating recreation benefits under different operating regimes, the Corps has developed functions relating recreation benefits to lake levels and river flow volumes. Mainstem recreation benefits are apportioned among 10 states, but over 75 percent of the total accrues in three states: South Dakota (36 percent), North Dakota (26 percent), and Nebraska (16 percent). Including Iowa (5.5 percent), four states account for over 80 percent of recreation benefits (USACE, 1998c).

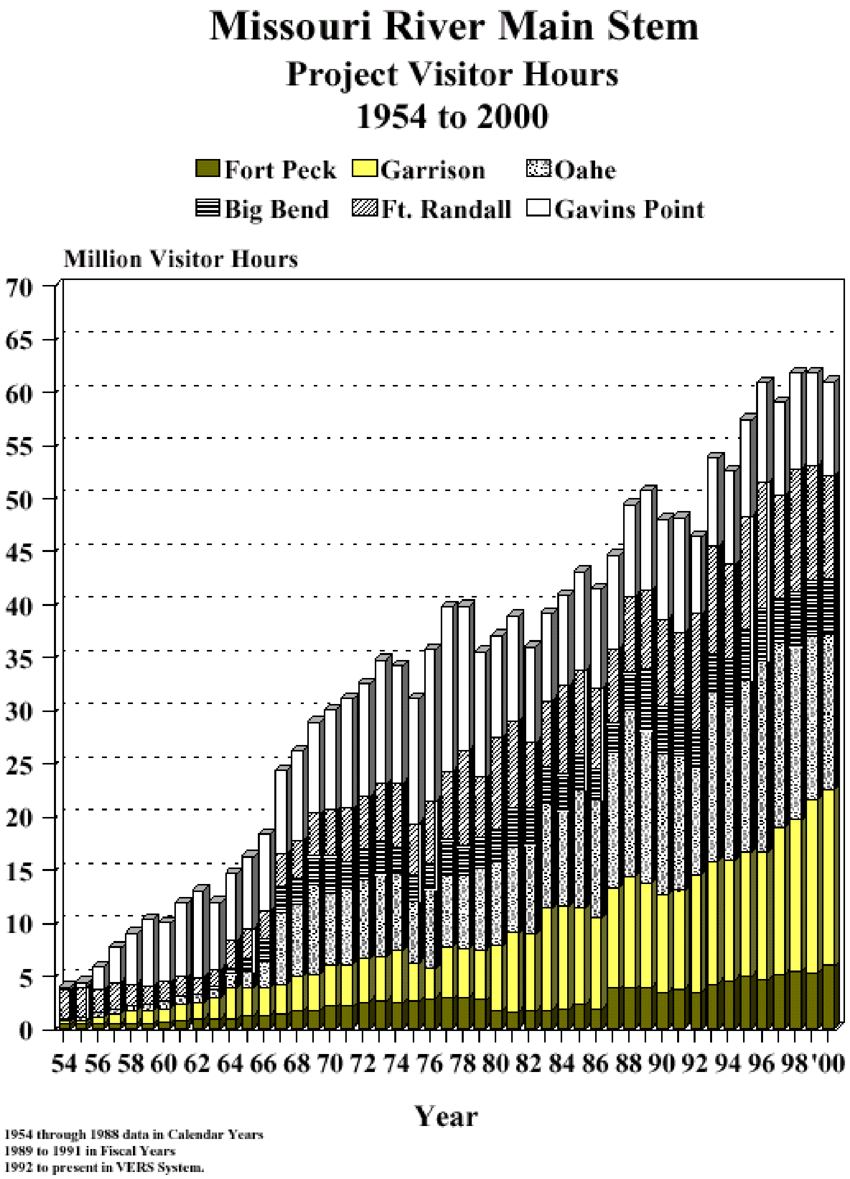

FIGURE 4.2 Recreational use at Missouri River reservoirs, 1954–2000.
SOURCE: USACE, 2000a.

Hydroelectric Power Production

All generating units had been installed and all reservoirs had reached operating levels in the Missouri River mainstem dams by 1967. Since then, power generation has fluctuated with water available. In 1998, power generation was 10 billion kilowatt-hours. This was 99 percent of the average annual production. In 1993, at the end of a drought, power generation was only half as much (USACE, 2000a). Figure 4.3 shows the record of hydropower generation from 1954 to 2000. The value of the hydropower produced is not maximized because releases through the powerhouses or from the dams must satisfy other project purposes like flood-damage reduction, navigation, and certain environmental objectives such as tern and plover nesting and recreational use of the river below the dams.

Hydropower benefits are based on the costs of power generated by alternative systems, usually thermal-electric. Hydropower revenues, as distinct from benefits, are not based on competitive rates charged for the power because some of the power generated goes to customers such as rural electric cooperatives at preferred (less than market) rates. Power from the Pick–Sloan Missouri Program goes to 329 customers in a six-state area. Customers include municipalities, federal agencies, federal and other irrigation projects, rural electric cooperatives, public utility districts, and private utilities. Power goes outside the basin through interconnections to the Southwestern and Bonneville Power administrations, as well as to other areas served by the Western Area Power Administration.

The Corps states that of all the project purposes that justify the Missouri River system, hydropower provides the largest national economic benefit, with an annualized value that was no less than $615 million in the Corps' study of operating alternatives (USACE, 1994c). Larger values were obtained when flows were modified for the environmental alternatives. Hydropower benefits accrue principally to municipalities (35.7 percent) and to rural electric cooperatives (40.7 percent). In the regional economic allocation, the principal benefiting states are Nebraska (27.3 percent), Minnesota (21.1 percent), and South Dakota (18.6 percent). North Dakota, Iowa, and Montana share the remaining third of benefits (USACE, 1998c). Existing hydropower facilities provide an average of 9.5 million megawatt-hours, or about 9 percent of the energy used in WAPA's Mid-Continent Area Power Pool. The six dams in the system—from Fort Peck to Gavins Point—harness 764 of the 1,090 feet of fall from the pool of Fort Peck to the tailwaters of Gavins Point. Nearly all of the water that flows into the Missouri River is used for power generation because flood storage is rarely spilled, and the irrigation withdrawals for the federal projects at Garrison and Oahe, which were expected to divert 3.8 million acre-feet annually,

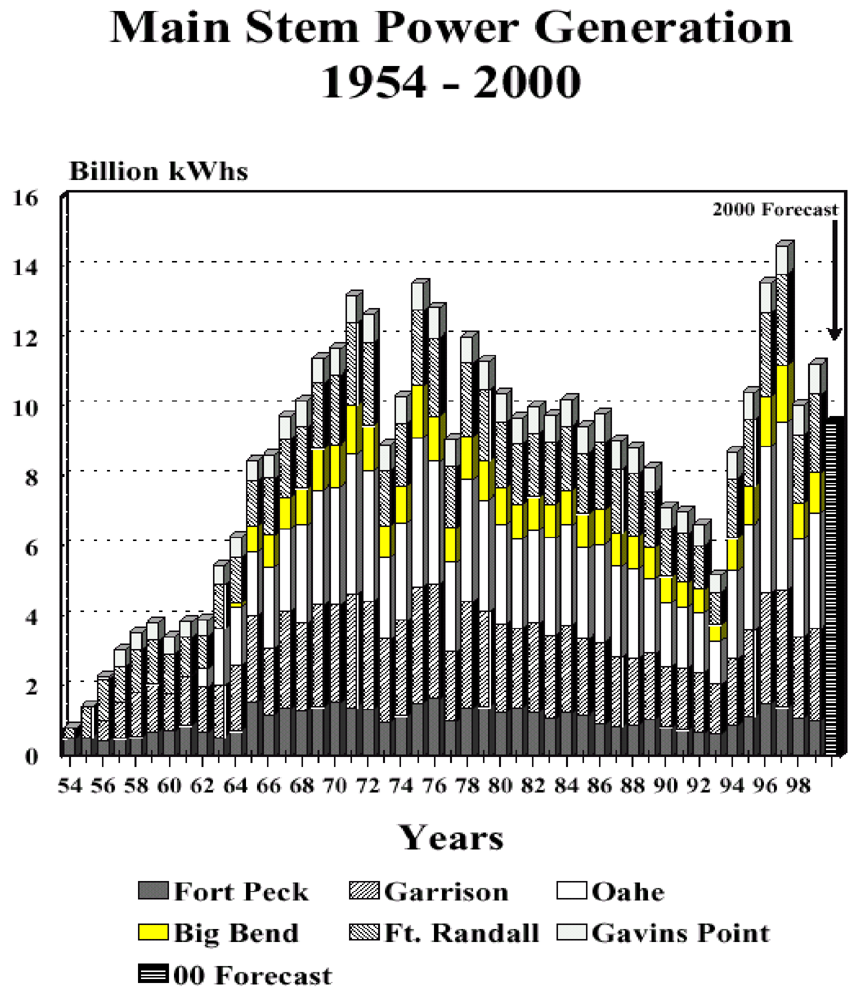

FIGURE 4.3 Hydropower generation from Corps of Engineers Missouri River mainstem dams, 1954–2000.
SOURCE: USACE, 2000a.

have not materialized. Irrigation developments on the tributaries were expected to divert an additional 2.5 million acre-feet annually but hardly more than 10 percent of these plans have been developed. Only at Gavins Point Dam do inflows exceed the discharge capacity of the powerhouse on a regular basis (i.e., 25 percent of the time).

Flood Damage Reduction

Figure 4.4 shows that cumulative flood damage prevented, as calculated by the Corps, rose rapidly in the 1990s. The years from 1986 to 1997 (inclusive) contained five years of annual runoff that exceeded 90 percent of the years in the historic record of runoff at Sioux City extending back to 1898. Whether hydrology is changing, channel geometry has altered, floodplain storage has diminished, or floodplain investment is increasing substantially—all of which are credible hypotheses—the cumulative record of flood damage prevented shows that by 1975, $1 billion in damages had been prevented; by 1998, this number had increased to $18 billion (in nominal dollars; USACE, 2000a).

Flood-damage reduction benefits are based upon a simulation of 100 years of hydrologic data, in which damage without the flood damage reduction features of the Missouri River mainstem dams are estimated. It is presumed that beneficiaries would pay at most this amount to avoid flood damage. Floodplain property values were current when the 1998 study was published. Urban property (not including land) valued at $17 billion and crops valued at $402 million were exposed to flood damage in a 500+ year flood along the Missouri from Fort Peck Dam to the mouth. The Corps

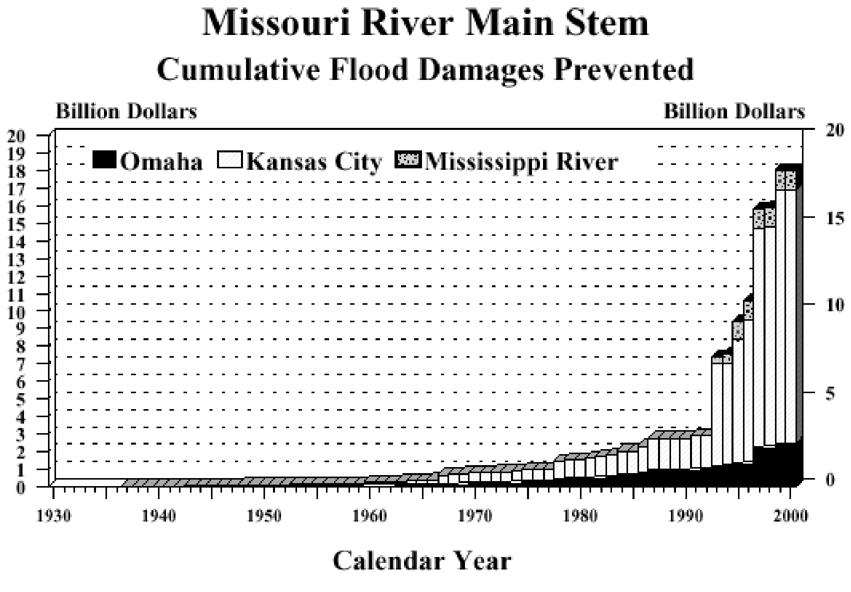

FIGURE 4.4 Cumulative Flood Damages Prevented on the Missouri River.
SOURCE: USACE, 2000a.

estimates that with existing flood storage capacity in place, the current water-control plan annually prevents an average of $414 million in damage (USACE, 1998b). Flood damage reduction benefits for the various sections are as follows: crops, 17.7 percent; residential, 25.8 percent; commercial/industrial, 35.25 percent; and roads/railways, 20.6 percent. The principal states benefiting from the annual benefits of 414 million are Missouri (25.4 percent), Iowa (24.8 percent), Nebraska (18.7 percent), and North Dakota (17.5 percent). Average annual benefits were reduced by about one percent for the environmental options that the Corps studied.

Flood damage is not proportional to the values of properties exposed to flooding. Simulations of flooding under current operations show that for the entire reach below Fort Peck, crops suffered 20 percent of the damage and residential and commercial properties suffered 80 percent of the damage. The distribution of damage is similar to that experienced in the 1993 flood (USACE, 1998b).

The Corps has evaluated two related types of damage from higher controlled flows that might create some flooding losses to agriculture from internal drainage problems and from higher groundwater. These losses are relevant to a comparison of alternative flow regimes. The current control plan inflicts some losses on agriculture, but some higher flows at certain times can increase the losses.

ACCOUNTING FOR ECOLOGICAL BENEFITS

The Missouri River–floodplain system consists of extensive ecosystems in and around the large reservoirs, open reaches of channel, and riparian floodplains. Some of these systems are recognized producers of recreational opportunities or agriculture. Some traditional ecosystems, particularly those representing the historical habitats of the pre-regulation Missouri, have been less well recognized for the social values provided through ecosystem services. As described in Box 1.1, many ecosystem services, such as fish, game, and aesthetic values, are not monetized and are not traded in markets. They thus tend to be underappreciated and undervalued by the public and by decisionmakers.

The concept of the flow of services has been recognized as a useful approach for evaluating the benefits of ecosystems (Daily et al., 1997, 2000; NRC, 1999a). Since the 1960s, federal guidance for water resource project evaluation has recognized that certain natural assets have value for “unique natural beauty and scenic, historical and scientific interest and improvement of habitat for wildlife and the preservation of rare species” (Senate Document 97, 1962). However, little effort was made to give these values parity with fully monetized costs and benefits. This recognition has been repeated in guidance from the U.S. Water Resources Council (WRC) in 1973 and 1983, and most recently in an executive order. The 1983 *Principles and Guidelines* added new methods for evaluating recreation benefits, which would cover a substantial portion of ecosystem services. Executive Order 12893 strengthened the benefit–cost requirement for federal agencies at the same time that it opened the way for wider consideration of environmental values by urging greater quantification of all types of benefits and costs, but also the use of qualitative measures reflecting values that are not readily quantified (Office of the President, 1994). However, the *P&G* document has not been modified to include such approaches.

To a real extent, ecosystem services have been equated with free services of nature without recognizing that certain of these services are becoming so increasingly scarce as to acquire value as economically scarce capital resources (Krutilla, 1967). An example of lost ecosystem services is provided in a quote from the Yankton Dakotian newspaper, dated Tuesday, August 5, 1862: "Katphish, of fabulous dimensions, are being taken from the placid waters of the Big Muddy about these times. A great many of them weigh two and three hundred pounds!" The reconceptualization of the basis of ecosystem value avoids the intractable problem of attributing intrinsic value to them and makes it easier to use common measures to compare ecosystem services to more traditional "monetized" river management benefits. The value of capital is defined by flows of useful services. Defining ecosystems as natural capital that yields useful services is the first step toward quantifying the value of ecosystems.

It is reasonable to believe that improving ecosystem health, resilience, or biodiversity makes the ecosystem more valuable, but that value cannot be measured directly without inquiring into the enhanced flow of services from the healthier ecosystem. For example, if certain steps are taken to restore ecosystems, what increases could be expected in sandbars, fish, and birds? What user values would accrue from the additional sandbars being utilized by duck hunters, by the additional sauger captured by anglers, and by the additional catfish harvested by commercial fishers for sale to local restaurants? What user values would accrue if birders had more places to watch birds and could see more nesting and migratory species?

Answers to these types of questions require quantification of the flows of ecosystem services and on the willingness-to-pay for these services. For example, thousands of birders travel to the Platte River each spring to witness the annual migration of Sandhill Cranes. State agencies along the river, such as Nebraska's Papio-Missouri River Natural Resources District, are promoting recreational uses. In Missouri, citizen groups such as the Friends of the Big Muddy and the Missouri River Communities Network promote public participation in improving recreational opportunities in the Missouri River floodplain. These efforts are consistent with national trends of increasing demands for outdoor recreation.

Although there are discussions and research within the Corps on contemporary environmental benefits analysis (Stakhiv et al., 2001), the *P&G* has not been modified to incorporate the concept of the benefits of ecosystem service flows. The Corps has not evaluated the economics of the flow of ecosystem services per se produced by the current and alternative operating plans for the Missouri aside from water-based recreation. Considerable effort has been devoted to measuring the willingness to pay for these kinds of goods and services in the past three decades, and there has also been progress in characterizing and modeling ecosystem service flows (USACE, 1996). Unfortunately, research in economics and ecology has proceeded mostly on separate tracks. But recent discussions produced a brief but useful guide for collaboration between these two, often disparate, disciplines for quantifying and valuing ecosystem services that could be used on the Missouri mainstem system (Daily et al., 2000).

SECONDARY BENEFITS

The committee recognized the dichotomy between primary and secondary benefits and the confusion this can cause in evaluating changes in Missouri River management. Primary benefits as discussed in the foregoing sections are the increases in output of real goods and services that accrue to the nation. Secondary benefits are the financial gains that accrue to the localities in which project activities of any sort may occur. Unless these distinctions are kept straight, discussions of the issues can become confusing. Box 4.2 sheds further light on this issue as it affects perceptions of benefits from the Missouri system.

TRADEOFFS AND CONSTRAINTS

Ecosystem Goods and Services

Authorization and construction of the Pick–Sloan dams involved tradeoffs for which the full economic and social costs have never been fully calculated or accounted for. The reservoir system replaced 755 miles of river valley with 5,940 miles of lake shoreline at base flood control pool with 989,000 acres of water surface at that pool level. When full, the total reservoir surface is 1.2 million acres (USACE, 2000a). The ecological services of 755 miles of unregulated river channel and floodplains were replaced with the ecological services of the reservoirs and the regulated river reaches between reservoirs. In the Missouri River's navigable, channelized portion, 300,000 acres of river channel, 600,000 acres of meander belt, and 1,900,000 acres of floodplain were projected to have been largely transformed by 2003 into agricultural, commercial, and transportation uses and navigation channel (USACE, 1981).

Box 4.2
Secondary Benefits

A criticism of water resources benefit-cost analysis has been the treatment of secondary benefits. Primary benefits from government expenditures such as water resources projects are the net increase in output of goods and services that accrue to the nation. That is, they appear in the national economic accounts or, in terms of the *P&G*, in the NED (national economic development) account. Secondary benefits are the financial gains that accrue to the localities in which project activities occur, but do not appear in the national economic accounts. They are the increase in business transactions experienced by a locality because, for example, recreational activity increases at a new reservoir. Secondary benefits are not real additions to NED. They merely represent the transfer of secondary economic activity from the regions that did not get the reservoir to the region that got the reservoir. After a contentious history, secondary benefits were ruled out of benefit-cost analysis, although the accounts are still kept as Regional Economic Development (RED) and are reported as instructed by the *P&G*.

This does not mean, however, that secondary benefits are unimportant in debates over the construction and operation of water resource projects like the Missouri system. To the contrary, the greatest interest in such projects usually comes from those who live, produce, and consume in the localities affected by the projects. Secondary benefits, not primary benefits, provide the motivations of these interested parties and their representatives in Congress. For example, commerce in the State of Missouri generates 50 percent of the primary benefits associated with navigation on the river or roughly $4 million annually in 1994 dollars in NED benefits (Iowa, Nebraska, and Kansas generate 17 percent, 14 percent, and 10 percent, respectively, of primary navigation benefits; USACE, 1994). The secondary impacts in Missouri of these benefits are estimated in 1993 dollars as $3.6 million in output, $0.7 million in income, and 26 jobs (USACE, 1998). These quantities of local output, income, and jobs, added to the transportation cost savings accruing to barge traffic generated by the state of Missouri, are the sources of political support in Missouri for navigation on the Missouri. This committee was told by spokespersons of the large benefits accruing to the navigation functions of the river system, but these benefits are technically only the secondary benefits inflated by an expenditure multiplier to reflect total regional economic development (RED) impacts for the entire United States. By drawing attention to the issue of secondary benefits, the committee signifies its awareness of the dichotomy between national and regional or primary and secondary benefits and the confusion this can cause if it is not handled rigorously in discussions of prospective changes in Missouri River management.

Current Operations

Tradeoffs and constraints are a part of daily operations in the mainstem system. For example, operating constraints are in effect at Fort Peck during the most critical icing conditions to prevent local flooding. As a result, the Western Area Power Administration must replace the power generation foregone with purchases on the open market to meet its distribution obligations. The assumption is that the cost of the power purchased is less than the value of the flood damage avoided. Most reservoir releases for purposes such as fish and wildlife conservation or flood reduction involve foregone power revenues. Existing and potential tradeoffs on the Missouri system include the following:

- Oahe Dam releases exceed the minimum 3,000 cubic feet per second during weekend daylight hours starting in early April to enhance fishing and boating during the recreation season.
- Releases are controlled to reduce flood damage in the reach downstream from Fort Randall Dam (Lake Francis Case) where there are homes and cabins in close proximity to the river.
- Hourly power peaking releases from Fort Randall Dam in June of 1999 were reduced at an unspecified cost in foregone power production. This action was taken to help prevent inundation of ten plover nests and forty tern nests in the reach between Fort Randall Dam and the Niobrara River.
- Baumel (1998) identified a potential tradeoff between supporting navigation on the Missouri River and using the mainstem Missouri River system to support navigation on the Mississippi River during low flows on the Mississippi.

Prospective Tradeoffs and Constraints

Many remediation measures aimed at restoring ecosystem goods and services will require different reservoir release patterns and thus will involve tradeoffs between existing and potential future benefits. The costs and benefits of the potential tradeoffs cannot be fully calculated at this point, but they can be described. For example, there may be beneficial effects on native fauna and flora, but there may be adverse effects on introduced fish species and possibly introduced flora, including agricultural plants.

The task will be to evaluate the changes in ecosystem service flows with and without the alteration in hydrology occasioned by an altered flow regime. There will be potential for flood damage on properties that are near the channel. This may lead to flood-proofing or relocation, costing less than the amount of the expected damage from flooding. Such risks of flood damage will have to be compared with the gains in ecosystem productivity. There may be drainage problems on some floodplains that have been converted to agricultural, industrial or domestic uses. The navigation season may be reduced, perhaps to differing degrees in different reaches, with differing consequences for recreational boating than for commercial navigation, and the maintenance of the uppermost segments of the navigation channel may not be optimal. There may be an increase in power production from the reservoirs as minimum pools are increased. There may be a reduced ability to maintain minimum flows later in the season to protect instream recreation and water supply intakes. Reservoir recreational uses may be affected. This list is not exhaustive and is not intended to be. Rather, it is intended to identify the breadth of expectations that have been raised for the Missouri River and to reflect what the Corps has already indicated in the 1994 and 1998 documents cited in this chapter. It may be appropriate to revisit the list of expectations or visions for the Missouri River and to simplify demands in order to preserve the most beneficial of the social values.

It is essential to look beyond the first approximations of negative impacts in evaluating tradeoffs. First approximations usually look at the worst possible case. When the question of adjustment and accommodation to the proposed change is pursued to the ultimate adjustment, the costs usually turn out to be much less than were indicated by the first approximation. For example, experience has shown that an industrial water user faced with increased costs for water withdrawals will experience higher costs immediately instead of later after greater efficiencies and other strategies are introduced into the water-using processes in the plant and in the waste stream. Experience has also shown that initial perceptions of costs may turn into benefits as production processes are reorganized.

The Corps' 1994 and 1998 studies provide clues to the types of tradeoffs involved. These studies compared the benefits from the current water control plan with benefits from alternatives that would restore habitat. From these studies, the committee drew the impression that flood damage reduction and water supply benefits would be minimally affected, that navigation benefits would be substantially reduced, but that hydropower benefits could increase considerably because of higher pool levels in the reservoirs. Unquantified ecosystem services would also increase. But given the small scale of navigation benefits, it would not be unthinkable to expect total system benefits to increase without accounting for ecosystem services. This is because likely increases of $10 million in hydropower benefits would offset the $2-3 million decrease in navigation benefits plus the small decreases in flood control and water supply benefits.

COMMITTEE COMMENTARY

Sizeable national benefits have been produced by the federal investment in the Missouri River Pick–Sloan Plan. This said, the smallest benefits among the authorized purposes along the mainstem come from irrigation and navigation. Although the annual national benefits from navigation appear to exceed the national costs of maintaining the channel, the expectation that the Missouri River would carry large and growing tonnages of agricultural products to market has not been realized. The reasons for this lie within the competitive disadvantage that the Missouri River basin faces in reaching agricultural export markets. This geographic reality could eventually mean that the cost of channel maintenance could exceed navigation benefits, at least in some upper segments of the channel.

Navigation economics are particularly vulnerable to the charge that they ignore the opportunity costs in terms of ecosystem services forgone both in the upstream reservoirs and in the downstream navigation channel. An opportunity cost on the order of $3 million in annual ecosystem benefits foregone would be sufficient to push navigation into the negative range of net national economic development (NED) benefits.

The Master Manual is the key document for distributing the benefits of the river and its reservoir operations. However, the procedures in the Master Manual used to produce the current suite of benefits largely reflect social values from the mid-twentieth century. As a result, the Master Manual may not adequately be meeting contemporary social demands, which place a greater emphasis on ecosystem benefits, water- and nature-based recreational pursuits, preservation of endangered habitats and species, the enhancement and conservation of biodiversity, and maintenance of the river corridor's cultural heritage. The Corps of Engineers recognizes that the current operations regime needs to be adjusted, having worked toward a revision of the Master Manual since the late 1980s.

There is today widespread recognition that the regulation of large rivers by dams and reservoirs has often resulted in losses of valuable ecological services. Although the environmental impacts of dams often have not been economically justified, many of those impacts can be reversed. On the Missouri River, there is a distinct prospect that a reversal of tradeoffs that would favor ecosystem restoration may be justifiable solely on the grounds that it represents an economic improvement on current mainstem dam operations. This, however, is not to deny that there may be winners and losers in a new operations scheme who will need to be carefully considered and perhaps compensated.

5

Adaptive Management: Enhancing Scientific Inquiry and Policy Formulation

For the past few decades regional resource and environmental policy and management have been in and out of decision gridlocks in many regions of North America, Europe, and Australia. When issues are polarized it is a time of deep frustration . . . The result can be ecosystem deterioration, economic stagnation, and growing public mistrust. Alternatively, the result can be an abrupt reevaluation of the fundamental source of the problems, a redirection of policy toward restoration, and implementation of a process of planning and management that provides continually updated understandings as well as economic or social product.

C. S. Holling, 1995

Adaptive management is an approach to natural resources management that promotes carefully-designed management actions, assessment of these actions' impacts, and subsequent policy adjustments. An adaptive management strategy explores ways to couple natural and social systems in mutually beneficial ways. It seeks to maintain or restore ecosystem resilience, which is defined as the capacity of key ecosystem structures and processes to persist and adapt over time in the face of natural and anthropogenic challenges (Gunderson et al., 1995; Light, 2001). Adaptive management was initially conceived as a way to overcome limitations of static environmental assessment and management approaches (Holling, 1978) and it encompasses efforts to improve understanding of how culture, policy, and social systems are interwoven and affect ecosystems from local to global scales (Gunderson et al., 1995; Light et al., 1989). The premises that underpin adaptive management are theoretically and practically appealing:

> Most principles of decision-making under uncertainty are simply common sense. We must consider a variety of plausible hypotheses about the world; consider a variety of possible strategies; favor actions that are robust to uncertainties; hedge; favor actions that are informative; probe

> and experiment; monitor results; update assessments and modify policy accordingly; and favor actions that are reversible (Ludwig et al., 1993).

Adaptive management recognizes that ecological and social systems are not static, but that they evolve in ways that are often unpredictable over both time and space. In addition to flux in natural systems, adaptive management assumes that human systems change and intervene, and thus induce subsequent ecological adjustments. These interactions then contribute to or detract from ecological stability and resilience.

Adaptive management seeks to narrow differences among stakeholders by encouraging them to implement new approaches that will allow people to live with and profit from natural ecosystem variability at socially-acceptable levels of risk (Light et al., 1989).

Adaptive management is characterized by the following components and assumptions:

- **It maintains and restores some degree of ecosystem resilience.**

Resilience represents an ecosystem's capacity for self-renewal. Resilient river systems contain a high degree of diversity of indigenous animal and plant life. The ecological diversity of the pre-regulation Missouri River was a function of 1) cut-and-fill alluviation, and 2) a high degree of hydrologic variability that provided spring and summer flood pulses, low flows at other times of the year, and that connected the river's main channel, floodplain, and backwaters. Recovery of some portion of these pre-regulation processes is essential to restoring resilience in the Missouri River ecosystem. Adaptive management programs commonly aim for partial restoration of natural ecosystem structure and functions.

- **It explicitly recognizes and seeks to profit from uncertainty.**

The search for certainty in ecosystem management is illusory: "Attempts to eliminate uncertainty are often delusory and counterproductive" (Holling, 1978). The formulation and perpetuation of ecosystem management policies based on certitude is not only conceptually unsound, but it is also likely to produce ineffective, if not ecologically destructive, policies. The quest for certainty creates dependency, and dependency fosters rigidity. Natural resources management policies that seek to eliminate uncertainty may enjoy initial successes, but in the long run often produce unexpected and disappointing results. Forest management policies in the western United States, for example, sought aggressively to reduce forest fires in the decades following World War II. These fire suppression policies for years were relatively successful at reducing fires. Over time, however, limitations of efforts to reduce the uncertainties (and dangers) of fire outbreaks became evident, as it was learned that occasional, smaller fires help control pests and limit the accumulation of biomass fuel (Pyne, 1998). Although more frequent, smaller fires were largely contained, these policies eventually resulted in massive forest fires, such as those in Yellowstone National Park in 1988 and in the Bitterroot Mountains of Montana in 1999.

Reality often changes faster than humans can comprehend. Our conception of reality is always partial and flawed, particularly at the scale of large, complex systems such as major river basins. As the speed, scale, and complexity of human-induced environmental changes increase, natural systems are pushed to the limits of stability, creating more change. The implication for management is clear. Managers cannot plan or regulate their way out of every problem, for what is not known or is poorly understood, the capacity to adapt must be added to the repertoire of management goals.

- **It promotes interdisciplinary collaboration and inquiry.**

In addition to biophysical concepts, sound ecosystem management also entails the consideration of social science issues. Economic values, public perception of and interest in ecosystem benefits, the use of scientific information by management agencies, and the ability of organizations to change and adapt are examples of social science topics that must be addressed in adaptive management. Physical, biological, and social scientists must thus collaborate on these and other science-policy issues within adaptive management programs.

- **It uses models to support decisions and collaboration.**

Adaptive management has a tradition of developing simulation models that are used to aid decision making. Expert opinions are used to inform model building and to help identify uncertainties before lengthy and costly data-collection efforts are undertaken. This modeling generally includes these steps:

- Bound the problem. Policy domains, key variables, time horizons, spatial area, and spatial resolution are identified and defined.
- Model invalidation. There is always something in the real world that an abstract model will fail to mimic properly. Modeling should therefore explore the limits of credibility.
- Simplification and compression. Adaptive management modeling should encapsulate understanding in clear and insightful ways.
- Develop policy alternatives. The goal is to explore the full range of options based on diverse perspectives, not create a perfect policy solution.
- Evaluate policy performance with a broad range of stakeholders. This step seeks to understand how alternative composite scenarios might perform under meaningful characterizations of management systems.

- **It seeks meaningful representation of a wide array of interest groups.**

Engaging a broad cross-section of people and organizations in developing vision and goals has been part of other programs for adaptive management and restoration of large U.S. river systems. In the Columbia River basin, for example, the Northwest Power Planning Council has since the early 1980s worked closely with tribal, state, and local governments in an effort to lower barriers to participation in Columbia River management decisions (Lee, 1989). In the Colorado River below Glen Canyon Dam, the federal Adaptive Management Work Group includes representatives from twenty-five stakeholder groups (NRC, 1999b). Forging river and aquatic ecosystem management objectives that represent and satisfy a broad range of constituents will be necessary in moving toward adaptive management in the Missouri.

- **It uses ecosystem monitoring to evaluate impacts of management actions.**

Adaptive management depends greatly upon environmental research and monitoring to evaluate the impacts of management actions. There has been much discussion regarding a potential program for monitoring ecological conditions and changes across the Missouri River basin. Decisions regarding which variables to monitor represent a serious challenge for new monitoring efforts. When such a program is initiated, it should not be delayed by this challenge. Missouri River ecosystem monitoring programs should revolve around a set of core variables relevant to river system management decisions. With evolving environmental conditions and scientific knowledge, variables important for policy formulation may change. Monitoring programs thus must have the flexibility to be able to identify and monitor new and potentially useful variables.

A conceptual modeling effort would provide an appropriate framework within which to consider specific monitoring needs and variables. If a Missouri River monitoring program is enacted, it should be closely coupled to adaptive management experiments and river management decisions. Science and monitoring efforts must not become ends in themselves, but rather should be clearly linked to management decisions and policy changes. It should also be recognized that monitoring and the larger adaptive management program, like other aspects of infrastructure operation and maintenance, will require a sustained commitment of resources.

COMMITTEE COMMENTARY

Successful implementation of adaptive management experiments and programs entails significant scientific, social, and political challenges. Adaptive management seeks to live with and profit from uncertainty and variability in natural and social systems. Adaptive management policies may challenge existing natural resources management policies, as these policies often seek to reduce or eliminate uncertainty and variability. The adaptive management paradigm posits that such efforts are counterproductive because some uncertainties in natural and social systems are simply irreducible. The Missouri River ecosystem, for example, contains ecological uncertainties and unknowns that scientific studies can reduce only so much, and the quest to eliminate variability from natural systems often has undesirable ecological effects. For example, the field of large river science has documented the ecological importance of the natural flood pulse. Reducing this natural variability reduces a key component of ecosystem health.

In its efforts to implement management actions to restore ecosystem variability, adaptive management programs may challenge political and economic structures that require reliability and that profit from tightly controlled ecosystems. Stakeholders with vested interests in tightly controlled systems may wield great political influence and may resist changes to traditional management policies. This resistance is often understandable, as adaptive management may ask some stakeholders to adjust the timing and level of benefits derived from system management. Examples from river management scenarios include hydropower distributors who are asked to generate less hydroelectricity in a controlled release from a reservoir, or towboat operators who are asked to suspend operations during planned high or low flows. These types of foregone benefits are among the larger costs of implementing adaptive management. Thus, implementing an adaptive management program that promotes a departure from the status quo usually requires tremendous political will. The context of Missouri River management contains powerful status quo interests, a history of mistrust and environmental decline, and current management controversies. Successful implementation of adaptive management would test the region's and nation's commitment to improving the system's ecological conditions and to realizing new opportunities in connection with these improvements.

Adaptive management also entails securing resources to establish monitoring programs, as well as enlisting scientists to initiate these programs and to interpret and communicate scientific findings. A commitment to long-term stakeholder participation requires firm and significant commitments of resources and time from participating interest groups, some of which may possess only limited resources. But resources are necessary to coordinate stakeholder and science meetings and related activities, as well as to defray administrative and facilitation costs. These undertakings will be complex and, at times, controversial. Advice from an independent, interdisciplinary scientific group will be useful in helping resolve differences of opinion regarding scientific and science policy issues. Moreover, adaptive management experiments are likely to challenge traditional interests and users, which are likely to resist changes that depart from the status quo. For adaptive management to work on the Missouri River, Congress must support the concept and all it entails—including experimentation and uncertainty—as well as provide the resources necessary to sustain a commitment toward recovering some Missouri River ecosystem benefits.

Adaptive management efforts will generally increase in complexity as the size of the ecosystem in which they are undertaken increases. No adaptive management program has been successfully implemented in an ecosystem on the scale of the Missouri River basin. The scale and the history of differences and conflicts in water development in the Missouri River basin constitute a significant barrier to the creation of flexible organizations able to promote harmony, conservation, equity, and environmental protection.

This committee harbors no illusion that adaptive management is a panacea for slicing through the basin's political and economic realities on the way to Missouri River recovery. The way forward will entail significant resources, as well as compromises that have not been a prominent part of the basin's water development history. It will also entail new governance structures. Despite the challenges, or perhaps because of them, it is time for fresh thinking and new approaches to Missouri River management. Although adaptive management may not represent the perfect solution for Missouri River management, concise paradigms for effectively managing large river systems have yet to be found. An effective adaptive management program will require political support for its implementation. Adaptive management will not immediately resolve all water resources conflicts in the basin, but it holds promise in helping move away from the current situation of ecological decline and policy paralysis.

An arrangement in which the Corps of Engineers was responsible for distributing benefits from dam and reservoir operations may have been appropriate in 1950. Today, however, these decisions should based on collaborative discussions between a broad range of stakeholders that include other federal agencies, the Missouri River basin states, tribal groups, environmental groups, floodplain farmers and other residents, the navigation industry, municipalities and citizen groups, and other nongovernmental entities.

6

An Alternative for Missouri River Recovery

> *The Missouri River was located in the United States at last report. It cuts corners, runs around at night, lunches on levees, and swallows islands and small villages for dessert. Its perpetual dissatisfaction with its bed is the greatest peculiarity of the Missouri. Time after time it has gotten out of its bed in the middle of the night with no apparent provocation, and has hunted a new bed, all littered with forests, cornfields, brick houses, railroad ties, and telegraph poles. Later it has suddenly taken a fancy to its old bed, which by this time has been filled with suburban architecture, and back it has gone with a whoop and a rush as if it had found something worthwhile. It makes farming as fascinating as gambling. You never know whether you are going to harvest corn or catfish.*
>
> George Fitch, 1907

Reversal of the Missouri River ecosystem trends described in this report will necessitate decisive and immediate management actions. The actions offered in this chapter can be viewed as a starting point for management agencies and other basin stakeholders. This chapter's action plan should not be interpreted as a set of rigid recommendations that must be closely followed, but rather as an example of the types of actions that might be taken and that might help stakeholders think broadly about the prospects for improving Missouri River ecology. Without notable changes to current Missouri River dam and reservoir operations policies, further ecological degradation is certain. If it is decided that restoring some portion of the Missouri River ecosystem's benefits is a valuable social goal—and recovery of some of those benefits may have significant economic and social values—this chapter provides a suite of possible actions that might be taken.

Although these actions are offered as suggestions, management actions of the variety and magnitude offered in this chapter are essential if ecological conditions are to improve. The degree to which the key physical processes—overbank floods and cut-and-fill alluviation—need to be restored in order to significantly improve river ecology is not exactly known. Scientific research provides sound knowledge of the ecosystem's fundamental physical and biological processes. But despite this scientific knowledge, details of the ecological responses to site-specific, habitat-based restoration efforts at the community level in the Missouri River ecosystem are not yet clear. The key uncertainties in the science of the Missouri River are in how the ecosystem will respond to efforts to improve river ecology

A RECOVERY ACTION PLAN

The Scientific Basis for Recovery

Restoring some portion of the Missouri River's pre-regulation physical processes is the key to ecological improvements. Movement toward river recovery will necessarily be incremental and should be framed within an adaptive management approach. Details of the timing and the extent of specific management actions should be established through collaboration among scientists, managers, and the public.

Restoration efforts should be implemented within a basinwide framework that recognizes the relationship of tributaries to the mainstem, of upstream areas to downstream areas, and of the river system's main channel and floodplain. The recommendation to cast management actions within a basinwide framework is not meant to imply that all actions should be conducted simultaneously across the basin. On the contrary, a more reasoned approach, consistent with an adaptive management paradigm, would be to first identify and implement management actions that appear to offer substantial ecological improvements with minimal disruptions to people and floodplain infrastructure (the "low hanging fruit"). Management actions that are taken should be conducted in a spatially-coordinated manner that considers mainstem-tributary, upstream-downstream, and main channel-floodplain relations through the entire river system.

Ecosystem processes that drive the ecology of the Missouri River include mainstem and tributary floods (and low flows) and cut-and-fill alluviation associated with meandering. The area in which increased meandering is most likely to produce rapid ecological improvements is the channelized portion of the river from near Nebraska's Ponca State Park downstream to St. Louis. Creation of unconstrained corridors that provide room for the river to meander in an erosion zone (annual wet edge to wet edge) also is crucial for program success. In those areas identified for adaptive management actions, steps should be taken to lower, remove, or set back hardpoints on the filling bank or revetments on the cutting bank to widen the annual erosion zone before changes in flows are prescribed. Broadening the dimensions of the erosion zone (also known as top-width) also increases floodwater storage capacity of the floodplain. This, in turn, reduces the risk of downstream flooding in high flows associated with dam releases that mimic the spring flood pulse. A substantial spring flood pulse in some stretches of the river would help provide the channel–floodplain connectivity that is ecologically important in large river–floodplain systems like the Missouri. Pioneer cottonwood and willow stands, along with more numerous snags, would increase roughness of the riverbed and floodplain surface and help decrease streamflow velocity. The erosion zone that would develop as a result of this action is required by native species, both in the river and on the floodplain, for their continued existence. Simply constructing man-made habitat to satisfy the life-requirements of complex organisms, without changes in fundamental physical processes, is not likely to yield substantial ecological improvements. Restoring some degree of natural river-based processes, like flooding and cut-and-fill alluviation, is essential to promote improved ecological conditions. The time frames in which there are likely to be noticeable ecological improvements are not known but are likely to vary throughout the river–floodplain ecosystem. The uncertainty of ecological responses to management actions provide further rationale for conducting these actions within an adaptive management framework that promotes an iterative process that includes actions, monitoring, evaluation, and learning.

Current Mitigation and Restoration Activities

Since the mid-1970s, the Corps has cooperated with the U.S. Fish and Wildlife Service and state conservation agencies to develop and implement projects to "mitigate the loss of fish and wildlife resources resulting from the construction, operation and maintenance" of the Missouri River navigation project, Sioux City to near St. Louis (USACE, 1981). Under other authorities and over this same period, the Corps has also carried out environmental restoration and monitoring activities along the lower Missouri River. The Corps has also carried out various environmental mitigation activities on the Missouri River mainstem designed to improve habitat and reduce the impacts of the dams on endangered species. In 2002, the Corps plans to evaluate the impacts of increased spring flows from Fort Peck dam on pallid sturgeon recruitment, spawning, and egg maturation.

The 1986 Water Resources Development Act (WRDA 86) authorized the Corps to develop habitat on 18,200 acres of existing state and federal land on the Missouri River floodplain and to acquire and develop an additional 29,900 acres of land. Under this authority, the Corps has to date purchased 23,549 acres of land and has developed habitat on 4,295 acres. It has also constructed habitat on 2,504 acres of existing lands. Action under WRDA 86 is scheduled to be completed in 2006 at an estimated cost of $80 million (USACE, 2001).

In the 1999 Water Resources Development Act, Congress authorized acquisition and development of an additional 118,650 acres of land over the next 35 years at an estimated cost of $750 million. To date, no funds have been appropriated under this authorization, and transmittal to the Congress of the plan proposed by the Corps is awaiting Office of Management and Budget action.

Under the 1986 authorization, restoration, and mitigation work has been completed at eight sites and is under way at nine sites, and acquisition is under way at nine additional sites. Projects include enhancement of flow through side channels and development of backwater areas, installation of pumps, and construction of control structures to create habitat. A coordination team representing the Corps, the U.S. Fish and Wildlife Service, and the Missouri River basin states identifies potential projects and prepares plans for their development. The Corps and officials from the state in which the project is located jointly assume duties for monitoring the impacts of these projects. Using other authorities (Section 1135, WRDA 86), the Corps, in cooperation with state and local agencies, has attempted to restore habitat at several other locations along the river's navigable section. Furthermore, in the conduct of its operations and maintenance, the Corps has made efforts to modify dikes and related water-control structures to increase their utility to aquatic species. Although the team has provided for inter-agency and interstate cooperation, the effort is not designed to consider an ecosystem-level approach to restoration.

To help evaluate the impacts of adaptive management actions, restoration projects and programs should be complemented by ecosystem monitoring. Along the Missouri River, however, relatively little funding has been made available to track the results of the restoration and experimentation that is being conducted. There have been efforts to obtain federal funding to establish a formal Missouri River Monitoring and Assessment Program (MOREAP). As this report went to press, the MOREAP had not been formally authorized.

One proposed mitigation activity worth noting is a substantial release of warm water from Fort Peck Dam in 2002. Recognizing the potential ability of higher and warmer flows to provide hydrologic cues for pallid sturgeon, the Corps has planned a $4.4 million test of flow modifications from Fort Peck Dam. An initial test will involve discharges of up to 15,000 cubic feet per second beginning in May, 2002 and is to last 30 days. In 2003, the Corps intends to evaluate a release of up to 23,000 cubic feet per second during the same spring period (by comparison, peak, sustained flows in the 1996 controlled flood at Glen Canyon Dam on the Colorado River were roughly 45,000 cubic feet per second; Webb et al., 1999). The initial test will examine the ability of the Fort Peck spillway to increase water temperatures and to pass the needed flows. The full test in 2003 is planned to address the same issues as the 2002 test, but with higher flows (USACE, 2001).

Along with the Fort Peck releases, several other projects contributing to Missouri River ecological improvements have been completed or are being implemented, including Boyer Chute (Nebraska), Hamburg Bend (Iowa), Louisville Bend (Iowa), Grand Pass Conservation Area (Missouri), and The Big Muddy Refuge (Missouri). These projects are encouraging steps toward improved ecological conditions. But to ensure success, such ecosystem restoration actions should be coordinated across the Missouri River basin. Consistent with the adaptive management paradigm, they should be conducted in a stepwise manner so that outcomes can be evaluated and used to help inform future actions. These actions should be assigned priorities and schedules, they should aim toward clear ecological restoration goals, and their outcomes should be evaluated as management experiments, the results of which should be used as feedback within an iterative, adaptive management process. Restoration actions taken to date along the Missouri River do not fully meet these criteria.

A Coordinated, Reach-Specific Approach

The following reach-specific plan represents only one of many sets of possibilities for designing a comprehensive approach to improve Missouri River ecology. Such an approach is needed because improvements can and should be made in all reaches to improve the ecological state of the entire Missouri River ecosystem. Management actions must be coordinated among reaches because action taken in one reach affects downstream flow and sediment conditions. Practical constraints to new management actions and the guiding philosophy of adaptive management suggest the utility of a stepwise approach. For example, removing impediments to channel-widening will need to precede flow management to effect lateral channel movement. Additionally, some management actions will need initial refinement at the reach level before being applied more widely. In particular, prescribing flows that induce desired rates of channel movement will require some experimentation, given the range of environmental and social uncertainties. Some reaches also may have a higher priority for recovery than others because ecosystem processes in those reaches may be more compromised. A comprehensive approach to ecological improvements on the Missouri River will require different approaches within different river segments (Figure 6.1 shows the Missouri River basin and the numbered river segments described below).

Segment 1 is the unchannelized reach between the headwater streams and Fort Peck Lake. Although much of this portion is considered the last remaining natural section of the Missouri River, Canyon Ferry Dam con-

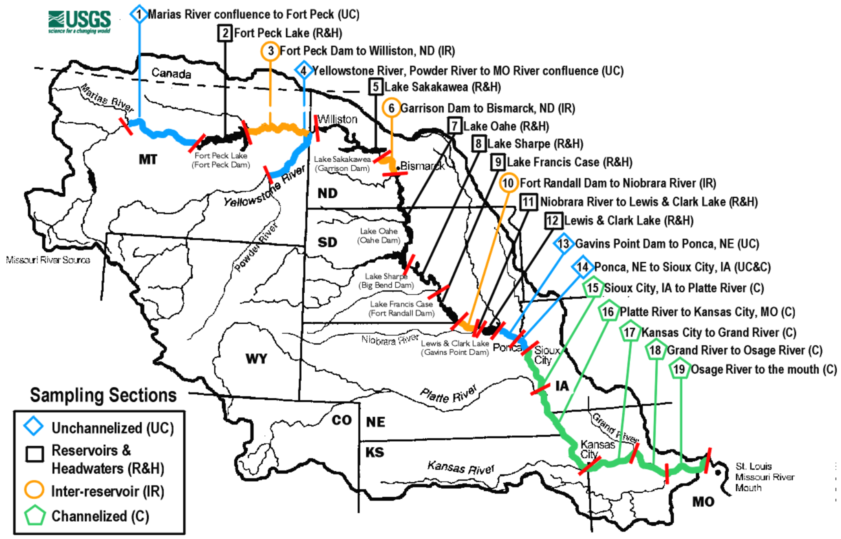

FIGURE 6.1 Missouri River basin and river reaches.
SOURCE: USGS, undated.

trols discharge along a large portion and is instrumental in reducing the flood threat in Great Falls, Montana, where there is considerable floodplain development. Some degree of alteration is possible in this reach, although a greatly altered discharge at Canyon Ferry would impact Great Falls. A better opportunity for restoring riverine processes may be along the Missouri River downstream from the Marias River confluence at Loma, Montana, and along the Marias River itself (Gardner, 1994). Tiber Dam lies about 80 miles upstream on the Marias River and is already managed to provide effective flows for the Marias (Gardner, 1998), but could also be used to enhance Missouri River flows (effective flows are peak flows necessary to re-establish cut-and-fill alluviation processes. Effective flows may or may not be equal to bankfull, but bankfull is usually assumed to control the form of alluvial channels; Gordon et al., 1992; Stanford et al., 1996). Lake Elwell was impounded to provide storage for irrigation and to help reduce flood damages. The Bureau of Reclamation operates the reservoir primarily for flood damage reduction, fisheries, and recreation (Montana Department of Fish, Wildlife, and Parks, 1998). There are no communities between Tiber Dam and the Missouri River at Loma, Montana. The level of ecological benefits restored could be substantial on both the Marias and Missouri rivers if Lake Elwell were used to restore riverine processes along both rivers upstream of Fort Peck. Restoration activities would enhance regeneration of cottonwood on the floodplain of both the Marias and Missouri rivers and enhanced habitats for native fish, including paddlefish, sturgeon, sauger, and chubs (William Gardner, Montana Department of Fish, Wildlife, and Parks, personal communication, 2000). Paddlefish and sturgeon are highly valued for both recreational fishing and for food value. Moreover, paddlefish eggs make high-quality caviar with high economic value, especially since sturgeon that have provided caviar in other nations have declined in abundance in recent decades. As a recreational fish, sauger are as highly-valued as are walleye; sauger would likely become far more abundant in this stretch of the river if more natural flow and habitat conditions were restored. Overbank flows would re-create active meandering on both rivers.

The opportunity to create active meanders in this segment is enhanced because the Missouri River downstream from the Marias River is designated as a national monument (and formerly as a federal Wild and Scenic River); thus, there is only minimal floodplain development. Removal of Tiber Dam represents an alternative. Although the losses of the benefits of Tiber Dam would have to be carefully evaluated and considered, removal of the dam would provide a substantial improvement in sediment transport and would provide exceptional benefits for native fish species upstream from the Tiber Dam site, as well as for the species of the lower Marias and the Missouri River (Zollweg and Leathe, 2000). Bovee and Scott (in press) examined six scenarios for delivering larger peak flows to this reach and found enough operational flexibility in the system to restore more natural flood pulses to improve cottonwood regeneration without greatly compromising other values.

Segment 3 includes the Missouri River downstream from Fort Peck Dam to the confluence of the Missouri with the Yellowstone River. This portion of the Missouri River has been impacted by cold water released from deep in the reservoir, by the elimination of effective flows, and by channel incision associated with the release of sediment-free discharge from the reservoir. The Montana Fish, Wildlife, and Parks Commission and the Corps of Engineers recently initiated a project to mitigate the cold, deep releases from Fort Peck Dam. Surface water would pass through the spillway and mix with deep turbine releases to increase seasonal tailwater temperature. Rock bank stabilization has been applied selectively to reduce bank sloughing. Significant bank erosion has precipitated landowner complaints, and subsequent bank stabilization projects have been constructed in the first 70 miles from Fort Peck Dam downstream to Wolf Point, Montana.

Another restoration opportunity is near Culbertson, Montana, about 45 miles upstream from the confluence of the Missouri and Yellowstone rivers (Mike Ruggles, Montana Department of Fish, Wildlife, and Parks, personal communication, 2000). There are erosion-control projects on the river's right bank; the left bank for much of this segment is on the Fort Peck Indian Reservation. A cooperative project between tribal groups and the Corps to promote overbank flooding and meandering would decrease the need for right-bank stabilization. It would also improve the prospects of increasing the amount of water spilled at Fort Peck for temperature mitigation and would create annual flows to maintain active meandering. Increased top-width beginning a short distance downstream from Fort Peck would help to remedy the sediment imbalance in the entire segment. Wider, shallower, and more turbid bends would also result in greater warming of the especially cool releases from Fort Peck.

The Milk River is a small, turbid, river that enters the Missouri River immediately downstream from Fort Peck Dam and provides an additional opportunity for recovering riverine processes. Stored Milk River and Saint Mary's River water is fully allocated for irrigation uses. However, tradeoff analyses could be conducted to assess the relative benefits of using the Milk River for irrigation versus using it to recover some portion of natural riverine processes. The Bureau of Reclamation could investigate the prospects of removing the diversions on the lower Milk River and could investigate altering Fresno Dam operations. Both actions would promote downstream transport of sediment stored in Fresno Reservoir. Fresno Dam could be used to contribute discharge for additional and possible overbank flows below Fort Peck Dam. In addition, the water would be warmer than the water coming out of Fort Peck Reservoir. The Montana Department of Fish, Wildlife, and Parks has developed management objectives for this reach, including maintenance of streambanks, channels, and seasonal flows from the Milk and Poplar rivers to enhance fish reproduction (Gilge and Brunsing, 1994). Warmer and more turbid flows would provide better habitat for pallid sturgeon and the native chubs that have declined in abundance in much of the lower Missouri. Paddlefish, sturgeon, sauger, and the buffalo species would likely increase in abundance in this reach with the types of restoration actions described above. These fishes would provide excellent recreational fishing opportunities, as well as improved availability of quality fish for human consumption.

Segments 3 and 4 include the Yellowstone River downstream from the Intake Diversion (a low dam on the Yellowstone River about 71 miles upstream from the Yellowstone-Missouri river confluence) and the Missouri River from its confluence with the Yellowstone to Lake Sakakawea. The diversion does not present a barrier to fish movement during high flows, but Forsythe Diversion, 237 miles upstream on the Yellowstone, may hinder fish passage (Penkal, 1992). The Yellowstone River's flow is uncontrolled, and both flood and base flows still occur (Backes and Gardner, 1994; Tews, 1993). Although some limited bank stabilization has been attempted along the lower Yellowstone River, the river still meanders to some degree. The free-flowing condition of the Yellowstone is crucial to this ecosystem's integrity (Fred Ryckman, North Dakota Game and Fish Department, personal communication, 2000). Moreover, flow enhancement at Fort Peck Dam and at the Milk River dams, in concert with natural flows from the Yellowstone River, would provide substantial ecosystem benefits from the Missouri River–Yellowstone River confluence to the upper end of Lake Sakakawea (Greg Power, North Dakota Game and Fish Department, personal communication, 2000). Top-width increases could be facilitated by removing existing erosion control devices and by adjusting Missouri River flows downstream from the confluence of the Missouri River with the Yellowstone River. The greatest environmental threats in this segment include water depletions and diversions from the Yellowstone (which have reduced Yellowstone River flows by about 24 percent), oil industry activities, bank stabilization, and shoreline development below the confluence (Power, 2000). These segments are currently strongholds for paddlefish, sturgeon species, and rare native chubs. Additional river meandering in this segment would regenerate early-successional plant communities, thereby enhancing both floodplain biodiversity and riverine fish abundance and recovery.

Segment 6 is the unchannelized reach downstream from Garrison Dam to Oahe Reservoir. This segment has been impacted by deep, cold-water turbine releases from Garrison Dam, by channel incision associated with sediment transport imbalance, and by selective bank stabilization. Because of the relatively short distance between Garrison Dam and Lake Oahe, and because of extensive floodplain development near Bismarck, North Dakota, opportunities for restoration actions here are limited compared to longer, undammed reaches farther upstream. However, increased top-width associated with active meanders and increased turbidity could mitigate cold water temperatures. Active meander subreaches interspersed among unaltered subreaches could be planned from the tailwater of Garrison Dam to Washburn, North Dakota, and from several miles downstream from Washburn to about Mandan, North Dakota. Another subreach with the potential to create active meanders exists several miles downstream from Bismarck to the upper end of Lake Oahe. The Heart River enters the Missouri River near Mandan, North Dakota. Heart Butte Dam impounds a large reservoir that has flood-control capability. The prospects of a controlled release from Heart Butte to enhance flows in the lowest subreach of this segment could be considered. Warmer, more turbid flows, resulting from river meandering and increased spring season discharge, would improve reproduction for all native fishes in this reach and would directly provide another recreational fishing base to enhance the valuable fishery resources in the large mainstem reservoirs.

Segments 10 and 11 include an unchannelized reach downstream from Fort Randall Dam to Lewis and Clark Lake. The segments have been impacted by the lack of effective and base flows, by sediment imbalance, by the elimination of primary energy sources (floodplain plant material, particularly from trees and grasses), by cool-water releases from Lake Francis Case, and by selective bank stabilization. But the segments still exhibit a landscape much like the pre-regulation Missouri River. Sand bars, islands, backwaters, and sidechannels are well-watered under current river operations. However, the biota reflect a different condition. Indices of the abundance of native invertebrates and fish are much lower for these segments than for even the channelized sections of the river (Hesse, 1999). These reaches have localized housing developments, but the floodplain is primarily agricultural land. The greatest constraint to recovering active meandering might be overcome by a program of sloughing easements. The segments were designated the Missouri National Recreational River in 1991, and the National Park Service completed work on a general management plan in 1997. The ecology of this entire segment would benefit greatly by recovery of active meanders, and Fort Randall Dam is well situated to assist in the recovery by providing restorative flows. Sand bar development would be enhanced. Pioneer cottonwood and willow communities would develop within the erosion zone on newly formed point bars. Warmer and more turbid flows, and changes to the timing of flows, could enhance native fish production in this stretch, especially for paddlefish, sturgeon species, and sauger. Higher spring flows could help create more sand bars, which were historically used by migrating waterfowl in the fall. Today, waterfowl simply fly past much of this segment and adjoining segments of the Missouri River. But these stretches are important destinations for anglers, and increasing waterfowl populations would provide enhanced recreational and aesthetic opportunities for both anglers and hunters.

This region is strongly rural and is experiencing a general population decline. Many residents are moving to larger urban areas farther downstream. Schools are unifying and consolidating, and many small businesses are closing. Greater abundance of fish and wildlife could provide an economic resource to help offset the regional decline in the number of small family farms. For example, these segments of the Missouri River are currently included in the national bass fishing tournament schedule. Additional backwater habitat would likely increase the abundance of largemouth bass and could attract more anglers to the region, providing a boost to the regional economy.

A delta in the upper end of Lewis and Clark Lake developed rapidly after the closure of Gavins Point Dam in 1955, as sediment from the Niobrara River was prevented from moving downstream (Johnson, 2002). The aggradation has increased the local flood stage, resulting in flooding on private land. Hydropower head has been compromised more quickly than expected. Alternatives for eliminating the sediment have ranged from dredge removal to a pipeline for transporting the soil to the waters directly below Gavins Point Dam. However, one possibly useful measure to move the sediment may be a "run-of-the-river" management plan. The lake could be drained in late fall, and the river would be allowed to cut through the delta throughout the winter and until early spring each year. The soft, easily-eroded sediment in the bed of Lewis and Clark Lake would likely erode in both vertical and horizontal dimensions, and be transported as the river meandered across this otherwise lake environment (similar actions have been enacted for over forty years at Spencer hydropower dam in Nebraska; see Hesse and Newcomb, 1982). An appropriately timed spring release from Fort Randall Dam would provide a small spring rise to Segments 10 and 11. This rise could be captured downstream by Gavins Point Dam and would serve to refill Lewis and Clark Lake for the following spring, summer, and fall. A sluice gate may be required at Gavins Point to facilitate downcutting of the transported sediment. Additional sediment would move downstream and could help restore the sediment balance in Segment 13.

Segment 13 includes an unchannelized reach from Yankton, South Dakota, to Ponca State Park in Nebraska. The segment has been impacted by the elimination of effective and base flows, by severe channel incision associated with sediment imbalance, and by selective bank stabilization. Few backwaters or islands exist along this reach. The segment was designated the Missouri National Recreational River in 1978, but development of a final general management plan was not completed until 1998. The National Park Service should incorporate recovery of riverine processes into the resource management plan (and the general management plan if necessary) that will be developed during the next few years. Much of the floodplain along this reach is agricultural land, but floodplain housing and recreational development are more extensive than in Segments 10 and 11. However, there are no large cities situated on the floodplain near the channel in this segment, with the exception of Yankton, South Dakota. Yankton is located on the Missouri River's left bank and is the first community below Gavins Point Dam. The riverfront in Yankton is about one mile long. Much of the river bank there is armored and there has been significant channel incision (as much as fourteen feet). The channel thus has a huge storage capacity (which exceeds the discharge of prospective releases from Gavins Point Dam) and the river bank could be fortified to ensure protection to the city if experimental flows are conducted.

Segment 13 (Gavins Point Dam to Ponca, Nebraska) would benefit ecologically with the recovery of some active meandering. Lateral sediment supplies would be engaged and sandbar development would be enhanced.

Pioneer cottonwood and willow communities would develop within the erosion zone on newly formed point bars. Primary energy supplies and turbidity would increase. Conveyance would be reduced, which would restore particulate organic matter in the hyporheic zone. Decreased conveyance would contribute to reduced flood stages downstream and would facilitate adoption of a programmed spring rise from Gavins Point Dam. The Wildlife Division of the Nebraska Game and Parks Commission is currently exploring opportunities to purchase lands from floodplain property owners willing to sell, and there are prospects for a sloughing easement program. In this latter program, private landowners are paid to allow river banks to erode. This would provide a demonstration project for restoring the action of meandering within several large bends of the river (Clayton Stalling, Nebraska Game and Parks Commission, personal communication, 2000). This segment contains an ecologically-important remnant population of paddlefish, sturgeon, and sauger that would likely increase in abundance with the restoration of flows that contained some of the river's pre-regulation character. Commercial fishing for non-game fishes is still practiced in this reach, but the abundance of fishes, and thus the catch, is low. Commerical catfishing was closed in this segment and on the next upstream segment in the early 1990s. Catfish, buffalo species, and a more economically viable commercial fishery could develop here in connection with enhancements in river ecology.

Segment 14 is the stabilized section between Ponca State Park and the confluence of the Missouri with the Big Sioux River. The segment was impacted by construction of channel-training structures, including stone hardpoints and revetments, by elimination of effective and base flows, and by extreme channel incision associated with sediment imbalance. This segment is a transition between the unchannelized condition of Segment 13 and the channelized portion of Segment 14. The original intent was to extend the navigable channel upstream to Yankton, South Dakota, but the project was never completed and commercial barge traffic does not extend into this stabilized reach of the Missouri River. Housing developments are common along the banks in this segment. Most houses are single-family dwellings used seasonally for river-related recreation. Nevertheless, there are opportunities to realign the controlling rock revetments to add 1,000 or more feet to the river's top-width. Mid-channel bars exist in this segment, but they are exposed only during low flows. Substantially increased top-width would provide for exposed sand bars and island development. More sand bars would almost certainly result in more paddlefish, sturgeon, sauger, and waterfowl, including the federally-endangered least tern and piping plover.

Segment 15 is the channelized reach between Dakota City, Nebraska, and Blair, Nebraska. The segment contains rock hardpoints, revetments, and chute closure structures, has experienced the elimination of effective and base flows, and sediment imbalance has resulted in channel incision. During normal navigation and nonnavigation season flows, nearly all features of the original river cross-section are disconnected, including side channels and backwaters, and there are only a few sand bars. The pre-regulation channel and erosion zone was as wide as 6,000 feet. The same zone today is 600 feet wide. Experimental reconnection of cut-off side channels is not feasible upstream from about the middle of this segment because of the degraded channel. Although there are facilities in this segment that require continued bank protection— such as rail and barge facilities, power plants and industrial parks, and bridge abutments—the majority of the bankline and the immediate floodplain is agricultural. The only city is Sioux City, Iowa, which lies upstream from the designated beginning of the segment.

An increase in the Missouri River's top-width has the potential to initiate ecosystem improvements, and this could be achieved through eliminating or lowering channel and grade control. Stabilized widths of the Missouri River channel currently range from 600 feet at Sioux City, Iowa, widening as one moves downstream, to 1,100 feet at St. Louis (Slizeski et al., 1982). Modeling investigations have demonstrated that widening the Missouri River channel downstream from Sioux City, by 400 feet would "virtually eliminate further bed degradation" (Holly and Ettema, 1993). Relations between increased top-width and enhanced biological diversity and production must be determined through careful experimentation and monitoring, but the evidence at hand suggests a starting top-width of roughly 1,100 feet. However, top-width might be increased to several thousand feet at sites like Omadi, Snyder, Glovers Point, Winnebago, Blackbird, Tieville, Middle Decatur, Lower Decatur, Louisville, Bullard, Soldiers, Tyson, and California bends. Most of these floodplain depressions lie directly adjacent to the present navigation channel. Land in some of these sites has already been acquired under the existing authority of the Missouri River Bank Stabilization and Navigation Mitigation Project or under Section 1135 of various Water Resources Development Acts. Increased top-width throughout this extensive segment could provide a substantial increase in available flood storage. Additional storage would reduce downstream flood stages during high flows and would therefore make it less problematic to release a spring rise from Gavins Point Dam. Extensive sand bar, island, backwater, and riparian habitats would develop in this segment. Pioneer cottonwood and willow and riparian wetlands would benefit many native fish and wildlife species and enhance currently dwindling plant biodiversity on the floodplain. This entire segment (not just selected bends) could be widened while simultaneously protecting important infrastructure.

The potential to enhance the abundance of native fishes is great in this segment, as the transformation of native habitat by human actions is as great here as in any other segment on the Missouri River. More importantly, this segment and the next downstream segment (segment 16) are adjacent to densely-populated parts of several bordering states. The demand for additional recreational destinations near urban centers is great. Significant enhancements in river ecology would likely result in marked increases in user-days for recreational fishing, commercial fishing, and hunting. Moreover, additional sand bars would provide excellent opportunities for swimming, camping, and other leisure activities.

Segments 16 through 19 include the channelized reach downstream from the Platte River in Nebraska to the Mississippi River. A two-tiered approach is one promising course of action for ecological recovery in these channelized segments. First, land riverward of the federal levees could be available for seasonal flooding each year. The federal levee system begins north of Eppley Airfield (Omaha) at about river mile 625 (upstream from St. Louis). This system was designed to protect farmland and developments landward—not riverward—of the levee. However, the land between federal levees and the river has been farmed, and expectations consequently arose to protect this land as well as those lands behind the levees. A programmed flood designed only to impact land riverward of federal levees is possible (Hesse, 1995). Navigation would be largely unaffected with this approach, at least upstream to Omaha.

Second, site-specific alteration to the spur dikes and revetments along this reach may be accomplished to increase top-width on a smaller scale than would be implemented in Segment 15. Recent modeling has determined that top-width may be increased at least 175 feet without jeopardizing navigation (USACE, 1999). However, this modeling was done for the Lower Decatur Bend reach where periodic grounding has occurred. Other subreaches downstream from Omaha, where cross-section depth is greater than necessary to support full-service navigation, may be widened by more than 175 feet without impacting navigation. The navigation channel could be widened to the maximum allowable extent throughout the entire segment while maintaining a functional navigation thalweg.

These hypothetical changes would entail tradeoffs, and compromises will be necessary; navigation upstream from Blair, Nebraska, may occur only during limited time periods or not at all, but navigation downstream of Omaha would not be impacted. Floodplain landowners and developers would be asked to accept permanent sloughing easements or flood easements in order to provide the necessary corridor to maintain a new, smaller floodplain within which the Missouri River would be allowed to meander (Box 6.1 describes efforts to create and expand the Big Muddy Wildlife Refuge in this stretch of the river). This would result in cut-and-fill

Box 6.1
The Big Muddy National Fish and Wildlife Refuge

The Big Muddy National Fish and Wildlife Refuge in the State of Missouri was established on September 9, 1994, "for the development, advancement, management, conservation, and protection of fish and wildlife resources" (16 U.S.C. 742f(a)(4)). As of 1999, the refuge contained 16,628 acres. The U.S. Fish and Wildlife Service has proposed expanding the refuge to cover 60,000 acres, through acquisitions from willing sellers and donors, to help reconnect the river and floodplain and to assist in the recovery of species and habitat. The Missouri River floodplain covers approximately 800,000 acres in the State of Missouri. Natural resource managers in the region judge that between 10 percent and 20 percent of floodplain habitat must be "restored to insure long-term health of the Missouri River ecosystem" (USFWS, 1999). If fully implemented, the 60,000 acres of Big Muddy would be added to similar efforts by the Corps of Engineers (14,600 acres) and the Missouri Department of Conservation (20,000 acres). The total average would constitute about 12 percent of the 800,000-acre floodplain.

The Missouri River floodplain in the State of Missouri has seen significant changes since settlement by the first Europeans over 200 years ago. Since the early nineteenth century, floodplain forest has been reduced from 76 percent of floodplain vegetation to 13 percent in 1972. During the same period, croplands increased from 18 percent to 83 percent of the floodplain. Agriculture's dominance in the floodplain suggests that the number of future willing sellers and donors will be a function of national and global grain markets, federal support for agriculture, and perhaps the severity of future floods.

Efforts to expand the Big Muddy face some of the economic, physical, and social constraints described in this report. The Fish and Wildlife Service's Final Environmental Impact Statement (USFWS, 1999) describes how floods and flood damage reduction strategies have affected their efforts: "The Great Flood of 1993 provided the impetus to revive the concept. Flood damages prompted many bottomland farmers to consider selling their land so they could either retire from farming or relocate their operations. . . . By 1996 many landowners and drainage districts were actively repairing damages and reclaiming flood devastated lands, even after a near repeat of the 1993 flood in 1995. By early 1997 landowner interests in 'selling out' had begun to wane. By the time the draft of this document was available for public review in October 1997, some landowner and private property rights groups had labeled this project a 'government land grab'."

alluviation and many features similar to those of the pre-regulation Missouri River, while other portions could be maintained much as they appear today.

It should be possible to improve Missouri River ecology by effectively widening the river and floodplain ecosystem by a few thousand feet in select areas. The same values would accrue to these downstream segments as in river segments just upstream. There are unmet demands for public fishing and hunting opportunities in and around urban centers like Kansas City, Omaha, and Saint Joseph, Missouri. As demonstrated in recreational surveys over the past few decades (Groen and Schmulbach, 1978; Mestl, 2001; Zuerlein, 1984), the Missouri River has great potential to become an important and economically valuable tourist destination.

CHANGING MISSOURI RIVER OPERATIONS

Legal Considerations

The issue of the Corps of Engineers' legal discretion to implement adaptive management strategies is complicated. Clearly, the Corps has no express duty to practice adaptive management—the concept is relatively new and did not exist when the Pick–Sloan Plan and subsequent legislation were adopted. Nor has the Corps been directed by Congress to implement specific adaptive management actions on the Missouri River. However, the lack of express authority to practice adaptive management does not preclude the Corps from implementing adaptive management actions ancillary to their general management authorities or pursuant to the protection of endangered species. In fact, and to the Corps' credit, the agency intends to release experimental flows from Fort Peck Dam. In addition, despite different legal contexts, ongoing restoration efforts such as those in the Columbia River basin, in the Florida Everglades, and on the Kissimmee River provide useful precedents for the Corps.

The Corps has seemingly taken inconsistent positions on its legal management authority. At times, it has claimed that the agency's legal flood-control and navigation enhancement duties, as defined in the Master Manual, leave it with limited discretion to experiment with different flow regimes. The Master Manual is, however, only a self-imposed limitation on its discretion. When its management authority has been challenged, it has taken the position that it has the legal discretion, virtually beyond review, to operate the reservoirs to balance among the competing multiple uses of the Missouri River. This claim is grounded in the Pick–Sloan Plan and subsequent legislation. As previously mentioned, the flows of the Missouri River are unallocated between the basin states and no states or individual parties have firm entitlements to any set release plan. There is no right to flood-control protection or to a minimum navigation flow, such as would exist within an interstate compact entitlement. This suggests that the Corps has considerable legal discretion to operate the system more flexibly than in the past. For example, in South Dakota's 1989 challenge to the Corps' failure to maintain high water levels at Lake Oahe, the Corps characterized the Master Manual as a non-binding "Guidance Document." Using this approach, fish and wildlife enhancement through adaptive management is a choice open to the Corps.

The Corps could not and should not make decisions that ignore its flood-damage reduction responsibilities. However, this committee did not find an irrevocable conflict between efforts at Missouri River ecosystem restoration and downstream flood damage reduction for urban areas at risk from floods. As adaptive management actions are implemented, great sensitivity must be shown to those most at risk from changed operations and a wide range of creative risk minimization options should be explored at all stages of the process. Current project beneficiaries may raise legal objections to any change in the operation of the system, but the ultimate success of these objections is not guaranteed. For example, beneficiaries of navigation flows do not have rights to any natural or artificial flows of the Missouri River. The "navigation servitude" posits that no individual may assert a property right to the flow of a navigable stream below the high water mark of the stream. The assumption has long been that the government may enhance or destroy the navigable capacity of a stream. Thus, the only navigation flow entitlement that could arise would be a by-product of a lawsuit alleging that the Corps acted without authority in the operation of a reservoir.

The Supreme Court has given the Corps great discretion in operating the Missouri River's Pick–Sloan dams. The status of navigation is further complicated by the 1944 O'Mahoney–Millikin compromise. The upper basin states maintain that the language of O'Mahoney–Milliken subordinates navigation to irrigation and precludes the recognition of any vested rights for a navigation channel depth. At a minimum, the compromise has long put lower basin states on notice that they face the prospect of diminished flows. As pointed out in a June 20, 2000 memorandum from the Congressional Research Service, the statute does not mandate any fixed navigation season and navigation is only one of several multiple uses for which the reservoirs are managed. The O'Mahoney–Millikin amendment contemplated that navigation would be subordinate to future irrigation withdrawals.

Some operational changes may increase the risk of downstream flooding. The legal issue is primarily whether the federal government is liable for property damages that result from intentional flooding. The federal government is not liable for "Acts of God" and Congress has enacted legislation that immunizes the federal government from all liability for damages arising from the operation of multiple purpose reservoirs for purposes related to flood control (33 U.S.C. Section 703c). However, if the government permanently inundates land above the high water mark in connection with a flood damage reduction project, the government must compensate the landowner because the servitude only extends to the high water mark. The fact that reservoir operations have non-flood control-related purposes does not deprive the government of its immunity so long as flood control is a purpose. However, as discussed in Chapter 2, if the Corps operates the reservoirs for a purpose unrelated to flood-damage reduction and causes flood damages, the government's immunity does not apply (Central Green Co. v. United States, 531 U.S.C., 2001). Congress always has the option to waive the government's immunity and compensate those injured by releases.

Legal objections to changed operations are further complicated because the Corps must subordinate dam operations to the protection of listed threatened and endangered species. The Endangered Species Act and most other environmental legislation were enacted after the Pick–Sloan Plan, and the usual legal presumption is that later acts modify prior acts. The courts have repeatedly held that the Endangered Species Act imposes a duty on the dam operating agency to comply with the mandates of the Act. Exceptions are made only if Congress specifically exempts the project or activity, or the agency obtains an endangered species exemption (Tennessee Valley Authority v. Hill, 437 U.S. 153, 1976; Klamath Water Users Protective Association v. Patterson, 191 F.3d 1115, 9th Cir., 1999).

Tradeoffs in Missouri River Management Decisions

A portion of the Missouri River's pre-regulation physical processes must be restored if the ecosystem's conditions are to improve. This will require changes to reservoir release schedules. Identifying tradeoffs that must be made to initiate these changes is a first step toward understanding how those changes may impact stakeholders. The following section provides examples of necessary tradeoffs to improve Missouri River ecology.

Ecosystem Services

Most tradeoff decisions regarding Missouri River management and dam operations relate to enhancing flows of ecosystem goods and services, which include a greater variety of wildlife of all kinds, including plants, increases in the production of rare and endangered species, and maintaining and improving production (e.g., fisheries, wildlife habitat) from wetlands and riparian areas. Although not always easily commensurable with the monetized values provided by the Missouri River ecosystem, such as navigation and hydroelectric power, many ecosystem services have great value. The values provided by these services, and the values that were lost with increasing Missouri River regulation in the 1950s and 1960s, have historically received limited attention in Missouri River reservoir management decisions. However, the enhancement of the Missouri River ecosystem may ultimately provide a broader and more sustainable set of benefits to the region and the nation than the current purposes for which the river is managed. The tradeoffs necessitated by changes in river management may even result in heretofore unanticipated benefits, while the costs of these tradeoffs can be reasonably well understood at present.

Floodplain Infrastructure and Residents

Over the years, the Missouri floodplains have become the site of agriculture, homes, businesses, and infrastructure that supports many large and small communities. Much of this development replaced fish and wildlife habitat. In many areas, ecologically-valuable wetlands have been isolated from river flows and separated from the river ecosystem by channel works and levees.

Some reconnection between the river and its floodplain is a key element in restoring ecological benefits. The Corps of Engineers has made efforts in its mitigation and restoration activities to carry out such reconnections; however, considerably more effort will be required to effect significant ecological improvements. Restoration activities accomplished to date have been done with the cooperation of landowners who have voluntarily agreed to sell land or have provided necessary easements. Future restoration efforts must recognize the necessity to work closely with floodplain residents to both minimize their vulnerability to floods and to ensure appropriate compensation for damages they might sustain or for property used in restoration efforts.

During the twentieth century, the prevailing aim of the nation's floodplain management policy was to reduce flood damages, primarily through levees, the upstream retention of water in reservoirs, and other structural measures. However, it has been recommended that a more appropriate goal is to maximize social benefits from our floodplains (NRC, 2000b; White, 2000). This latter goal discourages the location in the floodplain of new structures that are vulnerable to flood damage and encourages, where appropriate, the relocation from the floodplain of structures and activities that have been repeatedly damaged or are at high risk. Since the Mississippi flood of 1993, there have been roughly 13,000 voluntary property buyouts in the Mississippi and Missouri river basins (Michael Robinson, Federal Emergency Management Agency, personal communication, 2001).

A variety of mitigation measures can help people cope with flood damages. Floodproofing techniques, such as raising buildings or placing critical infrastructure above the first floor, are common and can greatly reduce flood damages. Flood insurance available through the National Flood Insurance Program (administered by the Federal Emergency Management Agency) is also available to some floodplain residents.

Relocation may represent a viable option in some instances. Displacement of people and infrastructure from floodplains must be conducted very carefully, as it may entail significant monetary and psychological costs. The process should be viewed as an opportunity to enhance social benefits from the floodplains, and a goal should be to assure that relocations make people at least as well off as they were before relocation. The costs of displacing people and infrastructure must be balanced against considerations such as the nature of the activity (farming and ranching; housing; industry) to be relocated. For some activities, location on the floodplain is essential; but if activities can be conducted elsewhere, relocation is a possibility. Voluntary relocation of floodplain structures has helped reduce federal payouts for flooded properties and infrastructure not covered by federal flood insurance.

Navigation and Changes in River Flows

The future of navigation on the channelized portion of the Missouri River represents a political challenge, as tradeoffs are likely necessary between maintaining full navigation service and reconnecting the river channel with its floodplain by changing flows at select times of the year. The economic consequences of tradeoffs between flow regimes, channel maintenance and recovery, and navigation are likely to be modest; however, this has nonetheless proven to be a politically contentious aspect of Missouri River management.

COMMITTEE COMMENTARY

The Missouri River, its floodplain, and its mainstem reservoir system provide many benefits, many of which are complementary. For example, reducing navigation flows to enhance ecosystem benefits may increase reservoir levels and lead to greater hydropower and recreation benefits. On the other hand, some benefits are at odds with one another. For example, efforts to restore natural physical processes and ecosystems may require occasional high flows from mainstem reservoirs that increase flooding and interfere with agricultural drainage.

When the dams and reservoirs were constructed, it was felt that these structures were changing the river system for the benefit of society. Menacing floods would be reduced or eliminated, navigation would be enhanced, irrigation waters would be stored, and hydroelectricity would be produced. There were costs at the time, but many of these were nonmarket costs and were seen as the price of progress. Environmental changes were viewed by some as being positive. The opinion that engineering structures would greatly reduce the ecosystem's benefits was expressed by a relatively small number of people. But over time, scientific understanding of the ecosystem and the impacts of human actions on the environment, as well as knowledge of the social benefits of environmental goods and services, have broadened and become more sophisticated. Social preferences have shifted greatly in the Missouri River basin over the past fifty years. The management regime of the dams and reservoirs, however, has been slow and more resistant to changes. Agencies responsible for operating the dam and reservoir system have attempted to appropriately adjust operations schedules, but have been caught between opposing stakeholder groups and have thus been limited in their ability to do so.

No one knows exactly what types of management actions must be enacted in order to restore socially-desirable levels of ecosystem benefits. But if further declines in the Missouri River ecosystem are to be halted and reversed, the time for implementing management actions aimed at ecosystem restoration is at hand. This chapter describes dozens of examples of prospective management actions that would improve ecological conditions. Details of those actions should be designed by citizens, scientists, and management agencies. They will necessitate trade-offs between stakeholders. Outcomes of these actions should be carefully monitored. Many actions will be conducted locally, but they should be coordinated in framework that considers all actions throughout the Missouri River ecosystem. They should not be seen as fixed policies, but rather as experiments that can be scaled back if results are disappointing, or enhanced if results are promising. In implementing management changes, there will be setbacks as well as pleasant surprises. Stakeholder cooperation in this setting presents a challenge, but it is essential if further declines in the ecosystem are to be averted. This report's final chapter provides advice on establishing and sustaining a multiple stakeholder group for Missouri River management.

7

Recovering the Missouri River Ecosystem

> *I am certainly not an advocate for frequent changes in laws and constitutions. But laws and institutions must go hand in hand with the progress of the human mind. As that becomes more developed, more enlightened, as new discoveries are made, new truths discovered and manners and opinions change, with the change of circumstances, institutions must advance also to keep pace with the times.*
>
> Thomas Jefferson, in a letter to George Washington, January 4, 1786

The Missouri River ecosystem is in a marked state of decline that is causing a reduction of goods and services and the potential loss of species. The decline has resulted in part from a series of federal actions that were designed to provide a suite of benefits thought desirable fifty years ago. Many of these benefits are still enjoyed today. However, that set of benefits does not fully satisfy contemporary preferences and needs. On the eve of the two-hundredth anniversary of the Lewis and Clark expedition, a critical crossroads regarding the Missouri River ecosystem's future is approaching.

This report recommends the use of an adaptive management approach to reverse the ecological decline of the Missouri River. Adaptive management is a relatively new approach and has not yet been fully implemented in the Missouri River. However, the concept holds promise in designing experiments that improve river ecology and that increase the flexibility of river management policies and organizations. Nonetheless, successful implementation of this paradigm, and progress toward a healthier Missouri River ecosystem, must address several challenges. This chapter identifies barriers and bridges to the successful implementation of adaptive management and provides policy, organizational, and scientific recommendations to help improve the condition of the Missouri River ecosystem.

BARRIERS TO IMPLEMENTING ECOSYSTEM RECOVERY

The implementation of Missouri River management actions designed to improve ecological conditions is stymied by institutional, social, historical, and physical factors. A management regime that actively promotes restoration actions in Missouri River dam operations has not been, until recently, part of traditional practices or goals, nor are such actions explicitly described in the Corps' Master Manual. Many Missouri River basin stakeholders are accustomed to a steady delivery of services. As in many U.S. river systems, historical inertia on the Missouri favors the status quo management regime and resists innovations and departures therefrom: "Inertia in the Missouri River basin is great, and the incentives to maintain the status quo strong" (Thorson, 1994).

The status quo, however, may not represent the straightjacket that many assume. Existing legislation may provide the Corps enough latitude within its operations and regulations to implement adaptive management actions for the benefit of river ecology. Although the Corps may have this latitude to experiment, the agency has had strong incentives to stabilize the river's hydrologic variability. A perception has thus developed that the Corps has limited legal ability to experiment with river operations. To an extent, this perception is perhaps true.

By the same token, the Corps has choices in deciding upon the means by which to meet the management ends defined in the Master Manual and other federal directives. The Master Manual, for example, does not preclude the use of experimental flows for meeting objectives defined in the Endangered Species Act or for ecosystem improvements. Nonetheless, perceived narrow limits on experiments act as a barrier to river recovery efforts. For example, recent proposals by the Corps to experiment with flows from Fort Peck Dam have elicited concerns regarding the Corps' legal authority to conduct such experiments.

The Corps could also pursue new practices to fulfill other emerging duties. The Corps, like all U.S. government agencies, is bound by federal environmental legislation such as the Endangered Species Act and has proposed management modifications to avoid violation of the Act. The Endangered Species Act and other statutes expand the Corps' discretion to make management decisions that incorporate species conservation and recovery and ecosystem restoration into its plans. The legislation reinforces the discretion that the Corps has under Pick–Sloan and its other authorities. In regard to prospective adaptive management activities, federal environmental laws such as the Endangered Species Act and the National Environmental Policy Act would not be suspended. Carefully designed and implemented adaptive management activities may constitute compliance with federal environmental duties.

A reliance on predictable patterns of benefit delivery has likely contributed to rigidity of the institutions and policies that govern Missouri River management. Towboat operators have come to depend upon a steady and reliable nine-foot river channel; their operations would be disrupted if the channel depth was twelve feet one day and six feet the next. The same operators that expect an uninterrupted 8-month navigation season may object to a divided navigation season consisting of two 4-month navigation periods. Most floodplain residents depend upon the river staying consistently within its banks. This dependence on predictable river flows inhibits management actions that seek to restore a degree of natural hydrologic variability of the river. Stakeholders who gain from the delivery of benefits, such as flood-damage reduction or navigation benefits, will naturally resist reductions in those benefits.

Finally, long-standing rivalries between upstream and downstream states, as well as between competing stakeholders, may also inhibit departures from the current management regime. Upstream stakeholders, for example, may resist experiments with upstream dams and reservoirs if it is felt that the ensuing benefits will accrue primarily to sections downstream. Similar tensions exist between beneficiaries such as recreational users, commercial shippers, and tribal groups. These tensions must be addressed if some of the river's ecological benefits are to be restored. With more information, it may be possible to show that benefits of some degree of ecosystem restoration exceed the losses and are fairly evenly distributed among stakeholders.

MOVING TOWARD RECOVERY: IDENTIFYING THE BRIDGES

To establish a foundation for an enhanced Missouri River ecosystem, resources must be devoted to reexamining the usefulness of conventional practices and policies in light of new demands and their understanding. Best practices of the past must be merged with the imperatives for some degree of river ecosystem recovery. New strategies and approaches must be instituted in order to initiate recovery of the river system's ecology. Four steps should be taken to help lay the groundwork for adaptive management strategies and actions.

1. Congress must legitimatize and empower Missouri River managers with the authority and responsibility to actively experiment with river operations that aim to enhance ecological resources. Actions must be designed to be large enough to show how the river's regime can be redirected to create and renew habitat. This may disrupt the current delivery of services, and care should be taken so that stakeholders are not subjected to undue stresses or surprises. As efforts are made to restore the Missouri's

natural processes, means of informing, and where necessary, safeguarding, mitigating, and compensating stakeholders who may perceive harm from changes in flows, must be developed and implemented as impacts become known. For example, the Corps' district office in St. Paul, Minnesota, did all of this in preparation for pool-stage manipulations in late summer, 2001, which were designed to improve habitat in the Upper Mississippi River.

2. A representative stakeholder committee should be empowered and convened by the appropriate agencies to develop a basinwide strategy, conduct assessments, review plans, and provide oversight of the implementation of adaptive management initiatives. This action in and of itself will require congressional action to articulate the division of authority among the Department of the Army, the Department of Energy, the Department of the Interior, the Environmental Protection Agency, the states, Indian tribes, and other relevant bodies.

3. Congress must require the development of long-term goals and short-term measurable objectives for adaptive management actions so that successes and failures can enhance public understanding.

4. Given our imperfect knowledge of ecological dynamics and social preferences, federal agencies must be mandated by Congress to work with stakeholders to build commitment to and acceptance of changes to the current patterns of benefits delivered from the river and reservoir system. In doing so, flexibility in the delivery of multiple services must be promoted.

PRINCIPLES FOR STAKEHOLDER INVOLVEMENT

Recovery efforts must include significant stakeholder participation and input. With appropriate incentives and thorough trust building, there may be greater stakeholder willingness to engage in ecosystem recovery efforts than anticipated. Without stakeholder input, there is a high risk of litigation and further gridlock that will limit progress toward improved ecological conditions. Stakeholder involvement must be carefully developed and should adhere to the following principles in order to improve the chances of success (Larry Spears, North Dakota Consensus Council, personal communication, 2000). The order of listing should not be misconstrued as representing a hierarchy of any sort, and all of the following recommendations are important to ensure the stakeholder group's effectiveness:

- **Participation by a broad spectrum of interest groups.**

Many groups have legitimate interests in shaping improvements of the Missouri River ecosystem. It would not be feasible for every group to participate in every activity. Some groups will have greater resources than others, and some groups may be more active (and vocal) than others. The challenge will be to ensure that the voices of all sectors of the public are heard—not just those of the most vocal or most influential sectors. Environmental groups, businesses, farmers, municipal and regional governments, and citizens from across the basin must be at the table for discussions.

- **Inclusion of tribal interests.**

Native Americans have a special place on the Missouri River and bring a unique perspective to discussions. As with participation by other groups, given the large number of tribes along the river, the tribes must select those who will represent the interests and knowledge of all tribes along the river and who will share what they learn with their larger community.

- **Continuous two-way communication with the public.**

Too often in public-involvement processes, participation by select groups is seen as providing adequate contact with the citizenry of the basin, expecting that these groups will keep the public informed and accept their comments. This does not always work. Provisions must be made for formal input from the public, as individuals or groups, and for dissemination of information to the public. Ongoing exchange between decision makers and the public should aim to build a relationship of mutual respect and trust.

- **Visible participation by federal, state, and tribal governments and non-governmental organizations.**

Participation in the process must not become onerous to the participants. They must see that those they represent and those that sponsor the process value their efforts. This may be demonstrated by the participation of key government personnel and non-governmental personnel, by formal recognition of the work of participants, and by agencies that actively support the concept of public involvement.

- **Support from an independent, interdisciplinary scientific panel.**

In its activities, the stakeholder group will be presented with considerable scientific information developed by technical personnel representing government agencies, other organizations, and individuals. Although some of this material will be clear and uncontroversial, other material may be confusing and contradictory to other information, or it may contain significant scientific uncertainties. Therefore, an independent and interdisciplinary scientific advisory panel is necessary to help clarify and resolve scientific inconsistencies and to provide scientific knowledge to the stakeholder group. An independent advisory panel can also help resolve legitimate differences regarding scientific studies, structure adaptive management experiments, interpret the results of management actions, and measure progress toward ecosystem recovery goals.

A challenge to both the scientific group and to the stakeholder group is to determine an appropriate set of environmental indicators, or baseline, against which to measure the impacts of management actions and progress of adaptive management efforts. A useful initial effort of the independent science group would be to identify a set of indicators to be used in developing an assessment of ecological status and trends in the Missouri River ecosystem.

- **Provision by the federal government, with support from the states and tribes, of secure funding for stakeholder involvement effort over the lifetime of the activity.**

If the effort is continuous, financial support to the effort must be continuous. Funds will provide administrative support to the process and to its participants, will support travel expenses in connection with stakeholder participation, and will support activities of the independent scientific advisory panel and the facilitation group.

- **Participation by representatives of Congress and of the state legislatures of Missouri basin states.**

Staff members from the offices of basin representatives and senators at the national level and their equivalents at the state level must remain in contact with stakeholders and provide them with information at the political level and reinforce legislative support for the efforts of the stakeholder groups.

- **Consensus decision making by the stakeholder group.**

In developing positions on key issues, the stakeholder groups must operate in a consensus mode. Operating under a majority-rule system would leave some parties perpetually unsatisfied with the outcome. Although developing consensus positions requires more time and experience than does majority rule, consensus decision making provides more sustainable and more widely acceptable results.

- **Bounding the process with defined goals and with timelines for their achievement.**

The stakeholder group must define its expected outcomes and develop the plans to move toward them so that progress can be measured and problems identified. Participating governmental bodies should review and concur with these goals and timelines.

- **Conduct of the activities of the governments in an open and transparent manner.**

  To many, the very presence of a stakeholder group would indicate openness. To others, however, openness and transparency require that the government agencies and the stakeholder group conduct their activities in a manner that enables the public to observe these activities. Modern communications systems, the Internet, and availability to the media can enhance this process.

- **Authentication of the stakeholder involvement process by governments in a formal document with all participating agencies as signatories.**

  Full understanding of the process and the level of commitment to the process must be clear to all participating agencies. A Memorandum of Understanding among the agencies serves to eliminate misunderstandings and provides the public a summary of what stakeholder involvement entails.

- **Provision of formal, independent facilitation for stakeholder group activities.**

  When any broadly based group gathers to conduct business, the success of the meeting depends largely on the manner in which the meeting is conducted. Stakeholder group participants will have neither the time nor the expertise to consistently lead all discussions. Facilitation by sponsoring government agencies raises questions of conflict of interest. Independent facilitation by experts would provide for efficient and unbiased discussion of the issues that must be considered.

This committee is aware of the history of efforts to enlist stakeholder participation in river system policymaking, both in the Missouri and in other U.S. river basins, and does not labor under the illusion that its recommendations represent the final answer to resolving differences of opinion among stakeholders. Because previous, similar efforts in the Missouri may not have yielded results that are satisfactory to all parties, however, does not mean that stakeholder cooperation is not possible in the Missouri. Moreover, several of this committee's recommendations—an independent science advisory body, formal facilitation, adequate and sustained resources from and participation by the federal government, mandated and formal input into Missouri River management decisions, equal participation by a spectrum of users that includes tribal and environmental interests—have not been adequately tested as part of Missouri River management decisions. This committee cannot predict the outcomes of its recommendations, but if implemented, they would represent the most vigorous and comprehensive effort to date to formally incorporate a range of stakeholder perspectives into Missouri River and dam management decisions.

SYSTEM-WIDE MANAGEMENT

A system-wide perspective on Missouri River management must be part of river recovery efforts. Management decisions on the Missouri River's tributaries should be part of integrated, system-wide management, as well as the necessary ecosystem-wide management (vs. species or site-specific perspectives).

This committee was charged to focus on the Missouri River ecosystem. However, river managers and scientists should not lose sight of the fact that the Missouri River mainstem is the ecological backbone of the larger Missouri River basin which includes tributaries like the Bad, Kansas, Little Missouri, Platte, and Yellowstone rivers. Objectives and management strategies for future Missouri River management will be enhanced to the extent that they consider the effects of these and other tributary streams on the Missouri's mainstem. Tributaries contribute extreme flows and sediments that have significant effects on the Missouri's mainstem, and these tributaries often serve as refuges for endangered and threatened species. Experimental flows and other management strategies on tributary streams may have ecologically positive effects on the mainstem and, in some cases, may be politically and socially easier to implement than new management actions on the mainstem.

This committee also discussed the Endangered Species Act's effectiveness in protecting select species. The ESA has had positive effects for many species and has often proved to be a useful mechanism in promoting environmentally sound management strategies. Nonetheless, the ESA has weaknesses, one of which is that it focuses on single species, rather than on ecosystem-level criteria or objectives to promote species recovery (Rohlf, 1991). Thus, although useful in some ways, the ESA in itself is not likely to provide a sufficient basis for marked Missouri River ecosystem improvements.

Protection and recovery of endangered species will usually be enhanced to the extent that recovery efforts are cast in terms of ecosystem-level restoration and protection, as opposed to protecting only the habitat of an individual species. This broader, ecosystem-level approach to species protection should be promoted and should be part of efforts toward Missouri River recovery.

RECOMMENDATIONS

The actions needed to move toward Missouri River ecosystem recovery cannot be simply defined or developed in a short time frame. The decision-making process will likely encounter intermittent successes and setbacks. It will require experimentation and adaptation of the knowledge gained in the process. It will require adaptive management. The U.S. Army Corps of Engineers, in equal partnership with other federal agencies (e.g., Bureau of Reclamation, Department of Energy, Fish and Wildlife Service, Environmental Protection Agency, National Park Service), the Missouri River basin states, Indian tribes, and representatives from relevant interest groups (e.g., agriculture, environment, municipalities, navigation, recreation) should immediately begin to develop and implement an adaptive management program designed to improve the conditions of the Missouri River ecosystem. To help resolve scientific uncertainties and to assure progress toward ecosystem recovery, an independent scientific peer review process should be a formal component of this stakeholder group. The stakeholder group should review other adaptive management efforts to learn about successes, failures, and potential management actions that could be usefully implemented in the Missouri River ecosystem.

Many administrative actions in the Missouri River basin connected with revision of the Master Manual and with improvements in habitat for endangered species are presently under way. These activities seek to define policies for the mainstem dams and reservoirs that would seemingly satisfy the requirements of the Endangered Species Act, mitigate habitat losses, and begin ecological restoration. Substantial ecological recovery will not be possible without considerable additional experimentation; thus, a range of options should remain open.

A moratorium on current efforts to revise the Master Manual should be enacted. The Corps of Engineers, as an equal partner in cooperation with other stakeholders in Missouri River ecosystem management, should be guided in its dam and reservoir operations by an adaptive management program designed to support improvements to the Missouri River ecosystem. When it is ultimately revised, the Master Manual should provide the flexibility to execute adaptive management actions, such as revising flows to emulate key elements of pre-regulation hydrology and geomorphology.

Adaptive management actions are likely to result in the disruption of benefits to some stakeholders. Experimentation should not mean a long-term reduction in benefits and should result in overall increases; the distribution of benefits, however, is likely to be incrementally different and thus questioned by some affected parties. Although some disruptions are welcome, the goal should be to focus on the distribution of gains, as well as the losses stemming from ecosystem renewal, and to come to terms with any glaring disparities in the new set of consequences.

This committee believes that the Corps of Engineers, within its current authority, has the ability to collaborate in developing and implementing an adaptive management program focused on the recovery of the Missouri

River ecosystem. Other federal agencies operating in the basin have similar latitude to collaborate in an adaptive management process. The committee believes that the Corps has demonstrated the latitude to make incremental adjustments, within the order of listing in paragraph 9-3 of the 1979 Master Manual, among project outputs in carrying out Missouri River ecosystem restoration. This committee encountered interests (in discussions with the Corps) that do not believe the Corps possesses this latitude and that additional authorization would be required to implement a substantial adaptive management program.

Therefore, to ensure clarity regarding authority, and to emphasize the need for a Missouri River adaptive management program, Congress should enact a Missouri River Protection and Recovery Act. This Act should clarify the authority of the Corps and of other agencies regarding collaboration as equal partners in this adaptive management effort. It should also provide the necessary fiscal resources—including administrative and facilitation resources—to ensure effective implementation of the Act and the achievement of its goals. The act should also provide for congressional oversight of the progress of the stakeholder group and its activities. Finally, in five years, Congress should commission an independent review of progress toward achieving the goals laid out in the findings and recommendations in this report for implementing adaptive management in the Missouri River ecosystem.

This recommended congressional action should proceed on a parallel track with efforts by the Corps and other stakeholders to begin management actions aimed at restoring some level of ecosystem benefits. These actions should be monitored to determine if they are producing the desired outcomes. The building blocks for a successful adaptive management program will ultimately include a clear set of goals and objectives for the Missouri River and its floodplain ecosystem. The adaptive management program should also have a clear legal foundation, as well as a clear means of dispute resolution. Given the history of conflict in the basin, congressional oversight is essential to ensure that the stakeholder group represents the broad spectrum of basin interests and that its activities are achieving desired results.

EPILOGUE

When the Pick–Sloan Plan was authorized in 1944 and the Missouri River dams were subsequently constructed, a premium was placed on producing hydroelectric power, on controlling floods, and on promoting regional economic and population growth. But since then, fundamental economic and social changes have produced a citizenry that places increasing value on outdoor recreation and on the environment. Furthermore, with the exception of its larger cities, much of the upper Missouri River basin is experiencing population declines. Shifting, declining, and emerging values challenge the U.S. Congress and public agencies to determine how the nation's ecosystems should be managed and how their benefits should be allocated.

The Corps of Engineers has always been responsible for deciding upon the release schedules from the Missouri River mainstem reservoirs. Although determining the optimal reservoir release patterns in a large system like the Missouri River basin was never easy, the Corps was able to reduce the primary system objectives to two: 1) the provision of a reliable 9-foot navigation channel, and 2) the minimization of flood damage. The operations decisions to fulfill these goals were made primarily by hydrologists and engineers. The Corps' mission was to serve these two primary purposes, and the agency has been challenged to balance the demands of a broader constituency of multiple users. Furthermore, dams and other water resources projects were not subjected to the high degree of economic and environmental scrutiny that they are today.

Over time, other benefits of the Missouri River and its mainstem reservoirs have emerged. Although there were always costs of operating the reservoirs, those costs have come into sharper focus in recent decades. Responsibility for reservoir operations still rests with the Corps, but these decisions have become more complicated and more controversial with economic and environmental changes and with shifting public values. The Corps of Engineers allocates the benefits derived from Missouri River mainstem reservoir operations to a variety of users and stakeholders. In response to their broader responsibilities, over the past three decades the Corps has enlisted biologists and economists to assist in developing reservoir operation schedules.

Missouri River reservoir operations represent a series of complex tradeoff decisions for the Corps of Engineers. This report has documented tradeoffs between the benefits of restoring and preserving natural ecosystem benefits versus the benefits of managing the river for flood damage reduction and navigation. Without a full understanding of the impacts, particularly those that affected river ecology, decisions were often made without full attention to their consequences. Nonetheless, consequences of these tradeoffs, insofar as they have resulted in significant losses of ecosystem services to society, must be viewed as costs of the prior and current management regime for the Missouri River.

Given the significant social and environmental changes since the 1950s, along the Missouri River a comprehensive reevaluation of the various benefits of the Missouri River ecosystem is in order. Interests that benefit from the status quo on the Missouri River will resist such reevaluations and changes to the current operations schedule. Other stakeholders call for significant changes in operations and consequent reallocation of benefits. The Corps of Engineers thus finds itself at the center of a struggle between competing interests that seek to increase or to hold onto their share of these benefits. Just as the construction and operation of dams resulted in a reallocation of the river's benefits, contemporary struggles demonstrate that changes in Missouri River reservoir operations may benefit some interests and individuals at the expense of others. These considerations help explain criticisms leveled against the Corps of Engineers in its efforts to revise the Master Manual and the strong emotions that surround changes in Missouri River reservoir operation decisions.

Should the release schedule of the mainstem reservoir system be adjusted in an effort to increase overall social benefits? And how should the tradeoffs be weighed? These complicated questions should be resolved with input from federal, state, local, and tribal interests. They are not purely technical, scientific questions; they equally include public values. However these questions are answered, the current degraded ecological conditions, the inability among the Missouri River basin states to reach consensus on desirable levels of river flows, and an inability to promptly revise the Master Manual are unsatisfactory. Moving beyond gridlock and toward river recovery and better cooperation between the basin states is a tremendous challenge, but one that must be addressed if ecological declines are to be reversed and the region and nation are to enjoy a broader set of benefits from the Missouri River ecosystem.

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Appendixes

Appendix
A

Missouri River Aquatic Species

TABLE 1 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 Their Preferred Habitat

Taxa	Trophic group	Habitat
Ephemeroptera		
Family Ephemeridae		
Hexagenia	Collector-gatherer	Backup, chute, soft
Ephemera	Collector-gatherer-predator	Backup, marsh
Pentagenia	Collector-gatherer	Chute, channel, hard
Family Polymitarcyidae		
Ephoron	Collector-gatherer	Chute, channel, clay
Tortopus	Channel border, clay	
Family Oligoneuriidae		
Homoeoneuria	Collector-filterer	Channel, sandbar
Family Tricorythidae		
Tricorythodes	Collector-gatherer	Channel, chute, sand
Family Caenidae		
Caenis	Collector-gatherer-scraper	Chute, channel border
Brachycercus	Collector-gatherer	Channel, chute, sand
Family Heptageniidae		
Heptagenia	Scraper-collector-gatherer	Channel border, chute
Pseudiron	Predator-engulfer	Channel sandbars
Stenonema	Scraper-collector-gatherer	Chute, backup, pools
Stenocron	Scraper-collector-gatherer	Channel border, chute
Anepeorus	Predator	Channel, chute, borders

TABLE 1 Continued

Taxa	Trophic group	Habitat
Family Leptophlebiidae		
Leptophlebia	Collector-gatherer	Backup, marsh, pool
Paraleptophlebia	Shredder-detritivore	Channel, chute, backup
Family Siphlonuridae		
Isonychia	Collector	Channel, channel border
Family Baetidae		
Baetis	Collector-gatherer-scraper	Channel, chute, sandbar
Pseudocleon	Scrapers	Channel, chute, sandbar
Centroptilum	Collector-gatherer-scraper	Pool, backup, sandbar
Heterocloeon	Scraper	Channel, channel border
Callibaetis	Collector-gatherer	Backup, marsh, puddle
Dactylobaetis	Scraper	Backup, marsh, sand
Family Baetiscidae		
Baetisca	Collector-gatherer-scraper	Chute, border, sandbar
Family Emhemerellidae		
Ephemerella	Collector-gatherer-scraper	Chute, backup, marsh
Trichoptera		
Family Hydropsychidae		
Hydropsyche	Collector-filterer	Chute, channel borders
Potamyia	Collector-filterer	Chute, channel borders
Cheumatopsyche	Collector-filterer	Chute, channel borders
Family Polycentropodidae		
Neuroclipsis	Shredder-herbivore	Chute, backup, marsh
Nyctiophylax	Predator-collector-filterer	off channel habitat
Cyrnellus	Collector-filterer	off channel habitat
Family Hydroptilidae		
Mayatrichia	Scraper	
Hydroptila	Piercer-herbivore	Backwater borders
Agraylea	Piercer-herbivore	Backwater borders
Family Leptoceridae		
Ceraclea	Collector-gatherer	All aquatic habitat
Nectopsyche	Shredder-herbivore	Chute, backup, borders
Triaenodes	Shredder-herbivore	Backup, marsh, puddle
Family Limnephilidae		
Pycnopsyche	Shredder-detritivore	Chute, backup, puddle
Family Philiopotamidae		
Wormaldia	Collector-filterer	Channel, chute
Family Brachycentridae		
Brachycentrus	Collector-filterer	Channel, chute
Diptera		
Family Chironomidae	Collector-gatherer-filter	All aquatic habitats
Family Tipulidae	Shredder-detritivore	All aquatic habitats
Family Tephritidae		
Family Tabanidae	Predator	Backup, marsh, puddle
Family Chaobordiae	Predator-engulfer	Backup, marsh, puddle
Family Culicidae	Collector-filterer-gatherer	Backup, marsh, puddle

TABLE 1 Continued

Taxa	Trophic group	Habitat
Family Simuliidae	Collector-filterer	Chute, channel
Family Mycetophilidae		
Family Ceratopogonidae	Predator-gatherer	Backup, marsh, puddle
Family Muscidae	Predator	All aquatic habitats
Family Tachinidae		
Family Stratiomiyidae	Collector-gatherer	Backup, marsh, puddle
Family Agromyzidae		
Family Cecidomyidae		
Family Empididae	Predator	off channel habitat
Family Sciaridae		
Family Dolichopodidae		
Family Psychodidae	Collector-gatherer	Backup, marsh, puddle
Family Ephydridae	Collector-gatherer	Backup, marsh, puddle
Family Phoridae	Predator	
Plecoptera		
Family Perlidae		
Acroneuria	Predator	Channel, chute, borders
Family Perlodidae		
Isoperla	Predator	Channel, chute, borders
Perlinella		
Perlesta		
Family Taeniopterygidae	Shredder-detritivore	Channel, chute, borders
Odonata		
Family Coenagrionidae		
Argia	Predator	off channel habitat
Ischnura	Predator	Chute, backup, marsh
Coenagrion	Predator	off channel habitat
Agrion	Predator	off channel habitat
Enallagma	Predator	Backup, marsh, puddle
Family Gomphidae		
Gomphus	Predator	Backup, marsh, puddle
Family Libellulidae	Predator	Oxbow, puddle
Family Lestidae		
Lestes	Predator	Backup, marsh, puddle
Family Aeshinidae	Predator	Backup, marsh, puddle
Family Calopterygidae		
Agrion	Predator	Chute
Coleoptera		
Family Halipidae	Shredder-herbivore	Backup, marsh, puddle
Family Dytiscidae	Predator	Backup, marsh, puddle
Family Gyrinidae	Predator	off channel habitat
Family Dryopidae	Scraper-collector-gatherer	Chute, channel, sandbar
Family Curculionidae	Shredder-herbivore	Backup, marsh, puddle
Family Helodidae	Shredder-herbivore	Oxbow, puddle, marsh
Family Hydrophilidae	Predator	All aquatic habitats

TABLE 1 Continued

Taxa	Trophic group	Habitat
Family Staphylinidae	Predator	Sandbar, dune
Family Elmidae	Collector-gatherer-scraper	Chute, channel, sandbar
Family Heteroceridae	Predator	Sandbar, dune
Family Carabidae	Predator	
Family Chrysomelidae	Shredder-herbivore	Backup, marsh, puddle
Family Coccinellidae		
Hemiptera		
Family Corixidae	Piercer	All aquatic habitats
Family Lygaeidae		
Family Nabidae		
Family Aradidae		
Family Tingitidae		
Family Mesoveliidae	Predator	Backup, marsh, oxbow
Family Cicadellidae		
Family Coreidae		
Family Naucoridae	Predator	Backup, marsh, oxbow
Family Pleidae	Predator	Oxbow, puddle, marsh
Family Notonectidae	Predator	Backup, marsh, oxbow
Family Saldidae	Predator	Backup, marsh, oxbow
Family Gerridae	Predator	All aquatic habitats
Family Hebridae	Predator	Backup, marsh, oxbow
Lepidoptera		
Family Pyralidae	Scraper-shredder-herbivore	off channel habitat
Homoptera		
Family Aphididae	Herbivore	Terrestrial-incidental
Family Cicadellidae	Herbivore	Terrestrial-incidental
Family Ceropidae	Herbivore	Terrestrial-incidental
Family Delphacidae	Herbivore	Terrestrial-incidental
Family Aleyrodidae	Herbivore	Terrestrial-incidental
Hymenoptera		
Family Formicidae	Parasitic	Terrestrial-incidental
Family Eurytomidae	Parasitic	Terrestrial-incidental
Family Pteromalidae	Parasitic	Terrestrial-incidental
Family Braconidae	Parasitic	Terrestrial-incidental

TABLE 2 Unionid mollusks collected recently from four river basins in eastern Nebraska draining into the Missouri River, and the Missouri River

Elkhorn River	Platte River	Big and Little Nemaha Rivers	Missouri River
Anodonta imbecillis	Anodonta imbecillis	Anodonta imbecillis	
Anodonta g. grandis	Anodonta g. grandis	Anodonta g. grandis	Anodonta g. grandis
			Anodonta g. corpulenta
			Anodonta suborbiculata
Anodontoides ferussacianus	Anodontoides ferussacianus	Anodontoides ferussacianus	
Strophitus u. undulatus	Strophitus u. undulatus	Strophitus u. undulatus	
Arcidens confragosus		Arcidens confragosus	
Lasmigona complanata	Lasmigona complanata	Lasmigona complanata	Lasmigona complanata
Lasmigona compressa		Lasmigona compressa	
Tritogonia verrucosa		Tritogonia verrucosa	Tritogonia verrucosa
Quadrula quadrula	Quadrula quadrula	Quadrula quadrula	Quadrula quadrula
	Quadrula p. pustulosa	Quadrula p. pustulosa	
Amblema p. plicata		Amblema p. plicata	
Fusconaia flava	Fusconaia flava	Fusconaia flava	
Uniomerus tetralasmus	Uniomerus tetralasmus	Uniomerus tetralasmus	
Actinonaias ligamentina carinata		Actinonaias ligamentina carinata	

TABLE 2 Continued

Elkhorn River	Platte River	Big and Little Nemaha Rivers	Missouri River
Obovaria olivaria		Obovaria olivaria	
Truncilla truncata		Truncilla truncata	Truncilla truncata
Truncilla donaciformis		Truncilla donaciformis	
Leptodea fragilis	Leptodea fragilis	Leptodea fragilis	Leptodea fragilis
			Leptodea leptodon
Potamilus alatus	Potamilus alatus	Potamilus alatus	
Potamilus purpuratus			
Potamilus ohiensis	Potamilus ohiensis	Potamilus ohiensis	Potamilus ohiensis
Toxolasma parvus	Toxolasma parvus	Toxolasma parvus	
Ligumia recta		Ligumia recta	
Ligumia subrostrata	Ligumia subrostrata	Ligumia subrostrata	
Lampsilis teres f. teres	Lampsilis teres f. teres	Lampsilis teres f. teres	Lampsilis teres f. teres
Lampsilis teres f. anodontoides		Lampsilis teres f. anodontoides	
Lampsilis radiata luteola	Lampsilis radiata luteola	Lampsilis radiata luteola	
Lampsilis ventricosa	Lampsilis ventricosa	Lampsilis ventricosa	
	Corbicula fluminea		
	Elliptio dilatata		

TABLE 3 Gastropoda and Bivalvia Molluscs Collected in 1855-1857 by Hayden During the Warren Expedition

Mollusc taxa	Mollusc taxa
Unio alatus	Unio levississimus
Unio luteolus	Unio asperimus
Unio rectus	Unio elegans
Unio zizzag	Unio anadontoides
Magaritana complanata	Anadonta ferussaciana
Lymnea elodes	Lymnea nuttalliana
Lymnea humilis	Lymnea haydeni
Lymnea kirtlandiana	Lymnea umbrosa
Lymnea lubricoides	Lymnea philadelphica
Planorbis bicarinatus	Planorbis trivolvis
Planorbis lentus	Planorbis parvus
Planorbis campanulatus	Physa heterostropha
Physa integra	Physa elongata
Physa ampularia	Psidium sp.
Cyclas sp.	Daphnia sp.
Amnicola porata	Amnicola lapidaria

TABLE 4 Fish species of the Missouri River and Its Floodplain with Preferred Habitat, Present Status, and Distribution and reference

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Ichthyomyzon castaneus, Sandbar depositional, Increasing exotic, MO-KS-NE, 5
Acipenser fulvescens, Sandbar, Rare and decreasing, MO-NE-SD, 2
Scaphirhynchus albus, Sandbar depositional, Listed and decreasing, MO-IA-KS-NE-SD-ND-MT, 2
S. platorynchus, Sandbar depositional, Stable to decreasing, MO-IA-KS-NE-WY-SD-ND-MT, 2
Polyodon spathula, Sandbar-Oxbow, Stable to decreasing, MO-IA-KS-NE-SD-ND-MT, 2
Lepisosteus osseus, Backups Marshes, Decreasing, MO-IA-KS-NE-SD-ND, 3
L. platostomus, Backups Marshes, Decreasing, MO-IA-KS-NE-SD-ND-MT, 3
Anguilla rostrata, Large snags Channel borders, Rare, MO-IA-KS-NE-SD, 1
Alosa alabamae, Main channel Snags, Rare, MO, 4
A. chrysochloris, Main channel, Rare, MO-IA-KS-NE-SD, 4
Dorosoma cepedianum, Backups Marshes, Stable to increasing, MO-IA-KS-NE-SD, 4-5
Hiodon alosoides, Sandbar pool Main channel, Stable to declining, MO-IA-KS-NE-WY-SD-ND-MT, 4-11
H. tergisus, Sandbar pool, Rare and declining, MO-NE, 5
Coregonus artedii, Reservoir, Exotic, SD-ND-MT.
Onchorhynchus kisutch, Reservoir, Exotic, NE-SD-ND-MT.
Onchorhynchus nerka, Reservoir, Exotic, SD-ND-MT.
Prosopium gemmiferum, Reservoir, Exotic, SD-ND.
Salmo aguabonita, Reservoir, Exotic, MT.
Salmo clarki, Reservoir, Exotic, WY-SD-MT.
Salmo gairdneri, Reservoir, Exotic, MO-KS-NE-WY-SD-ND-MT.
Salmo trutta, Reservoir, Exotic, MO-NE-WY-SD-ND-MT.
Salvelinus fontanalis, Reservoir, Exotic, NE-WY-MT.
Salvelinus namaycush, Reservoir, Exotic, SD-ND,MT.
Thymallus arcticus, Reservoir, Exotic, WY-SD-ND-MT.
Osmerus mordax, Reservoir, Exotic, NE-SD-ND.
Esox americanus, Backups Marshes, Uncommon, MO-NE, 7
E. lucius, Chutes Flowing Marshes, Increasing to reduced, MO-IA-KS-NE-SD-ND-MT, 12-7
E. masquinongy, Reservoir-Tailwater, Exotic, MO-NE-SD.
Carassius auratus, Backups Marshes, Exotic, MO-KS-NE-SD-ND-MT.

Cyprinus carpio, Main channel Backups Marshes, Exotic, MO-IA-KS-NE-WY-SD-ND-MT.
Hybognathus hankinsoni, Sandbar, Uncommon, MO-IA-KS-NE-WY-SD-ND-MT, 1
H. nuchalis, Sandbar depositional, Uncommon, MO-IA-KS-NE-WY-SD-ND-MT, 1
H. placitus, Sandbar depositional-Channels, Uncommon, MO-KS-NE-WY-SD-ND-MT, 3
H. argyritis, Backups sandbar-depositional, Uncommon, MO-KS-NE-SD-ND-MT, 3
Macrhybopsis aestivalis, Sandbar Main channel, Increasing to decreasing, MO-IA-KS-NE, 5-6
M. gelida, Sandbar Main channel, Rare, MO-IA-KS-NE-WY-SD-ND-MT, 3-6
M. meeki, Sandbar Main channel, Rare, MO-IA-KS-NE-SD-ND-MT, 6
M. storeriana, Backups, Reduced, MO-IA-KS-NE-SD, 6
Notemigonus crysoleucas, Backups Marshes, Uncommon, MO-IA-KS-NE-SD-ND-MT, 1
Notropis atherinoides, Sandbar Main channel, Increasing, MO-IA-KS-NE-SD-ND-MT, 3-5

TABLE 4 Continued

N. blennius, Main channel margins, Increasing to reduced, MO-IA-KS-NE-WY-SD, 5-3
N. buchanani, Backups, Stable to increasing, MO-KS, 5
N. dorsalis, Chute sandbars, Reduced, MO-IA-KS-NE-WY-SD, 3
N. hudsonius, Gravel bars Backups Reservoirs, Stable-exotic, IA-NE-SD-ND-MT.
N. lutrensis, Backups Marshes Sandbars, Stable to increasing, MO-IA-KS-NE-WY-SD-ND, 5
N. spilopterus, Sandbar Main channel, Increasing non-native, MO-IA-NE-SD.
N. stramineus, Sandbar, Stable to decreasing, MO-IA-KS-NE-WY-SD-ND-MT, 5
N. volucellus, Sandbar Main channel, Stable, MO, 5
Pimephales notatus, Backups Marshes, Stable to increasing, MO-KS-IA-NE, 5
P. promelas, Sandbar depositional Backup, Stable to increasing, MO-IA-KS-NE-WY-SD-ND-MT, 5
Ctenopharyngodon idella, Backups Marshes Main channels, Increasing exotic, MO-IA-KS-NE-SD.
Hypophthalmichthys molitrix, Backups Marshes Main channels , Increasing exotic, MO-IA-KS-NE-SD.
Hypophthalmichthys nobilis, Backups Marshes Main channels , Increasing exotic, MO-IA-KS-NE-SD.
Carpiodes carpio, Backups Main channels, Stable to decreasing, MO-IA-KS-NE-WY-SD-ND-MT, 5
Carpiodes cyprinus, Backups Main channels, Uncommon, MO-IA-KS-NE-WY-SD-ND, 7
Carpiodes velifer, Backups, Main channels, Uncommon, MO-IA-KS-NE, 7
Cycleptus elongatus, Main channel Chutes Large snags, Stable to declining, MO-IA-KS-NE-SD-ND-MT, 3-4
Ictiobus bubalus, Backups Marshes, Reduced and declining, MO-IA-KS-NE-SD-ND-MT, 7
I. cyprinellus, Backups Marshes, Reduced and declining, MO-IA-KS-NE-SD-ND-MT, 5-7
I. niger, Backups Main channel, Uncommon to rare, MO-IA-KS-NE, 7
Moxostoma macrolepidotum, Rock, Main channel Chute, Stable, MO-IA-KS-NE-WY-SD-ND-MT, 7
Moxostoma erythrurum, Rock Pools Turbidity, Uncommon, MO-IA-KS-N, 7
Ictalurus furcatus, Main channel Large snags, Reduced to uncommon, MO-IA-KS-NE-SD, 8
I. melas, Backups Marshes, Reduced, MO-IA-KS-NE-WY-SD-ND-MT, 5
I. natalis, Backups Marshes, Reduced, MO-IA-KS-NE-SD-ND-MT, 7
I. punctatus, All habitats, Stable, MO-IA-KS-NE-WY-SD-ND-MT, 7
Noturus flavus, Rock Main channel margins, Unknown, MO-IA-KS-NE-WY-SD-ND-MT.
N. gyrinus, Depositional Backups, Unknown, MO-IA-KS-NE-SD-ND.
Pylodictis olivaris, Main Channel Large snags, Stable to declining, MO-IA-KS-NE-SD, 8
Lota lota, Main channel Large snags, Rare, MO-KS-NE-WY-SD-ND-MT, 9
Fundulus kansae, Backups Sandbar Main channel, Reduced, MO-KS-NE-WY, 1
F. notatus, Backups Sandbar, Increasing-exotic, MO-KS.
Gambusia affinis, Backups, Stable-exotic, MO-KS.
Labidesthes sicculus, Pool, Common to rare, MO-NE, 1-7
Morone chrysops, Sandbar pools, Stable-exotic, MO-IA-KS-NE-SD-ND.
M. mississippiensis, Backups, Uncommon, MO, 1
Ambloplites rupestris, Rock Large snags, Stable, MO-IA-NE-WY-SD-MT, 7
Lepomis cyanellus, Backups, Uncommon, MO-IA-KS-NE-WY-SD-ND-MT, 7

TABLE 4 Continued

L. gibbosus, Backups, Rare, MO-IA-NE-WY-ND-MT, 7
L. humulis, Backups, Uncommon, MO-IA-KS-NE-SD-ND, 7
L. macrochirus, Backups, Reduced, MO-IA-KS-NE-WY-SD-ND-MT, 5
Micropterus dolomieui, Rock, Increasing-exotic, NE-SD.
M. punctulatus, Main channels, Rare to stable, MO-KS-NE, 5
M. salmoides, Backups, Reduced, MO-IA-KS-NE-WY-SD-ND-MT, 7
Pomoxis annularis, Backups, Stable to decreasing, MO-IA-KS-NE-WY-SD-ND-MT, 5-7-11
P. nigromaculatus, Backups, Stable to decreasing, MO-IA-KS-NE-WY-SD-ND-MT, 7-11
Etheostoma nigrum, Backups, Reduced, MO-IA-KS-NE-WY-SD-ND, 7
Perca flavescens, Backups, Stable to declining, IA-KS-NE-WY-SD-ND-MT, 7-11
Stizostedion canadense, All river habitats, Reduced and declining, MO-IA-KS-NE-WY-SD-ND-MT, 5-10
S. vitreum, Sandbar pools Reservoir, Stable but mostly non-native, MO-IA-KS-NE-WY-SD-ND-MT.
Aplodinotus grunniens, Sandbar pools Main channels, Stable to increeasing, MO-IA-KS-NE-SD-ND-MT, 5

NOTES: 1. Pflieger (1975), 2. Hesse and Carreiro (1997), 3. Hesse et.al. (1993), 4. Hesse et.al. (1989), 5. Pflieger and Grace (1987), 6. Hesse (1994a), 7. Hesse (1983-1993), 8. Hesse (1994c), 9. Hesse (1994d), and 10. Hesse (1994b), 11. Hendrickson and Power (1999), 12. Hill et.al. (1997)

Appendix
B
State and Federal Rare, Threatened, or Endangered Species of the Missouri River Floodplain[1]

Plants
*Western Prairie Fringed Orchid (Platanthera praeclara)
*Mead's Milkweed (Asclepias meadii)
False Articulate Foxglove (Tomanthera auriculata)
Hayden Rockcress (Rorippa calycina)
Spreading Yellowcress (Rorippa sinuata)
Small White Lady's Slipper (Cypripedium candidum)
American Ginseng (Panax quinquefolius)
*Prairie Bush Clover (Lespedeza leptostachya)
Alpine Rush (Juncus alpinus)
Spring Ladies Tresses (Spiranthes vernalis)
Mud Plantain (Heteranthera limosa)
Missouri Ballcactus (Coryphantha missouriensis)
Yellow Fritillary (Fritillaria pudica)
Spiny Naiad (Najas marina)

Mussels
Spectacle Case Pearly Mussel (Cumberlandia monodonta)
Scaleshell (Leptodea leptodon)

Federally listed species are indicated by *.

[1] From Whitmore and Keenlyne, 1990.

Fish
Lake Sturgeon (Acipenser fulvescens)
*Pallid Sturgeon (Scaphirhynchus albus)
Sturgeon Chub (Hybopsis gelida)
Flathead Chub (Hybopsis gracilis)
Sicklefin Chub (Hybopsis meeki)
Lake Chub (Conesius plumbeus)
Paddlefish (Polyodon spathula)
Blue Sucker (Cycleptus elongatus)
Crystal Darter (Ammocrypta asprella)
Alabama Shad (Alosa alabamae)
Short-nosed Gar (Lepisosteus platostomus)
Black-nosed Shiner (Notropis heterolepis)
Silverband Shiner (Notropis shumardi)
Ghost Shiner (Notropis buchanani)
*Topeka Shiner (Notropis topeka)
Pearl Dace (Semotilus margarita)
Burbot (Lota lota)
Brassy Minnow (Hybognathus hankinsoni)
Finescale Dace (Phoxinus neogaeus)
Northern Redbelly Dace (Phoxinus eos)
Mooneye (Hiodon tergisus)
Northern Pike (Esox lucius)
Highfin Carpsucker (Carpoides velifer)
Plains Killifish (Fundulus zebrinus)

Insects
*American Burying Beetle (Nicrophorous americanus)
Regal Fritillary Butterfly (Speyeria idalia)
Dakota Skipper Butterfly (Hesperia dacotae)
Tawny Crescent Butterfly (Phyciodes batesi)
Six-banded Longhorn Beetle (Dryobius sexnotatus)
Noctuid Moth (Schinia indiana)

Reptiles
Massasauga (Sistrurus catenatus)
Yellow Mud Turtle (Kinosternon flavescens flavescens)
Alligator Snapping Turtle (Macroclemys temminckii)
Texas Horned Lizard (Phrynosoma cornutum)
Great Plains Skink (Eumeces obsoletus)
Eastern Hognose Snake (Heterodon platyrhinos)
Smooth Softshell (Apalone mutica)
Falsemap Turtle (Graptemys psuedogeographica)

Birds
*Interior Least Tern (Sterna antillarum)
*Piping Plover (Charadrius melodus)
Snowy Plover (Charadrius alexandrinus)
Mountain Plover (Eupoda montana)
*Whooping Crane (Grus americana)
*Bald Eagle (Haliaeetus leucocephalus)
*Peregrine Falcon (Falco peregrinus)
Swainson's Hawk (Buteo swainsoni)
Ferruginous Hawk (Buteo regalis)
*Eskimo Curlew (Numenius borealis)
Long-billed Curlew (Numenius americanus)
Migrant Loggerhead Shrike (Lanius migrans)
White-faced Ibis (Pelgadis chihi)
Swallow-tailed Kite (Elanoides forficatus)
Red-shouldered Hawk (Buteo lineatus)
Cerulean Warbler (Dendroica cerulea)
Doublecrested Cormorant (Phalacrocorax auritus)
Trumpeter Swan (Olor buccinator)
Osprey (Pandion haliaetus)
Common Loon (Gavia immer)
White Pelican (Pelecanus erythrorhynchos)
Marsh Hawk (Circus cyaneus)

Mammals
Swift Fox (Vulpes velox)
*Gray Bat (Myotis grisescens)
*Indiana Bat (Myotis sodalis)
River Otter (Lutra canadensis)
Red Flying Squirrel (Glaucomys volans)
Spotted Skunk (Spigale putoris)
Red Flying Squirrel (Glaucomys volans)
Spotted Skunk (Spigale putoris)

Appendix
C
Biographical Sketches of Committee Members

Steven P. Gloss is the director of the Biological Resources Program at the Grand Canyon Monitoring and Research Center in Flagstaff, Arizona. Dr. Gloss is a member of the Water Science and Technology Board and was a member of the WSTB Committee on Grand Canyon Monitoring and Research. Dr. Gloss' research interests include water resources policy and management, aquatic ecology, and fisheries science. He is currently studying these issues in the Platte River system. Dr. Gloss received his B.S. degree from Mount Union College, his M.S. degree from South Dakota State University, and his Ph.D. degree from the University of New Mexico.

Robert Davis has most recently been associated with the Institute of Behavioral Science at the University of Colorado. He was the head of the Economic Staff in the Office of the Secretary of the Interior for nine years. His areas of expertise are natural resource economics, environmental policy analysis, water resources planning, and methods of benefit-cost analysis. His Ph.D. thesis is generally considered the first publication on contingent valuation, a method in wide use today to quantify environmental benefits and damages. Dr. Davis has served as an advisor to foreign governments, has served in faculty positions at several universities and has served on the staff of Resources for the Future, Inc. Dr. Davis received his B.S. degree and his M.S. degree from the Ohio State University and the MPA and Ph.D. degrees from Harvard University.

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*Dr. Gloss accepted his current position in September, 2001. When this study began, he was with the University of Wyoming.

David Ford is the chief executive officer of David Ford Consulting Engineers in Sacramento, California. Dr. Ford's areas of expertise include hydrologic engineering, water resource systems analysis, and decision support systems. He has been a consultant to the U.S. federal and foreign governments and was a Fulbright scholarship recipient. Dr. Ford served on the WSTB Committee on Grand Canyon Monitoring and Research. He received his B.S. degree, his M.S. degree, and his Ph.D. degree, all in engineering, from the University of Texas.

Gerald Galloway is the secretary of the United States Section of the International Joint Commission in Washington, D.C. Dr. Galloway has served as a consultant on a variety of water resources engineering and management issues to the Executive Office of the President, The World Bank, the Organization of American States, the TVA, and the U.S. Army Corps of Engineers. Dr. Galloway is a former dean of the Academic Board (Chief Academic Officer) of the United States Military Academy. Dr. Galloway holds master's degrees from Princeton, Penn State, and the U.S. Army Command and General Staff College. Dr. Galloway received his Ph.D. degree in geography from the University of North Carolina.

Larry Hesse is the chief scientist and vice-president of River Ecosystems, Inc., and River Corporation, both located in Crofton, Nebraska. Mr. Hesse was previously employed as an aquatic research biologist and large river ecologist for the Nebraska Game and Parks Commission (1974–1994). Mr. Hesse's research experience has included work with the federal Upper Colorado River recovery program for endangered fish, as well as dozens of Missouri River fisheries studies for the federal government and private sector. He has authored roughly 100 journal papers, federal aid reports, books, and popular articles on Missouri River fisheries and water management. Mr. Hesse received his B. A. degree in ecology from Wayne State College and his M. A. degree in aquatic ecology from the University of South Dakota.

Carter Johnson is a professor of ecology in the Department of Horticulture, Forestry, Landscape & Parks at South Dakota State University. Dr. Johnson's primary research interests are in streamflow regulation and riparian ecosystems, restoration of ecological and economic sustainability of western rangelands, and global climate change and prairie wetlands. Dr. Johnson has conducted most of his research in the Missouri River Basin. He received the W. S. Cooper Award in 1996 from the Ecological Society of America. Dr. Johnson received his B.S. degree from Augustana College (Sioux Falls, SD) and his Ph.D. degree from North Dakota State University.

Peggy Johnson is an associate professor of civil and environmental engineering at Pennsylvania State University. Dr. Johnson received the National Science Foundation Young Investigator Award in 1992 and currently serves on the Executive Committee of the American Society of Civil Engineers. Her research areas include river channel stability, hydraulic engineering, and river mechanics, on which she has authored dozens of peer-reviewed papers. Dr. Johnson received her B.S. degree from New Mexico State University and her M.S. degree and her Ph.D. degree from the University of Maryland.

Kent Keenlyne is a retired wildlife manager who resides in Pierre, South Dakota. Dr. Keenlyne was a U.S. Fish and Wildlife Service Biologist from 1971 to 1996. Among other duties, Dr. Keenlyne served as the coordinator for the Upper Missouri River Conservation Committee and the Missouri River Coordinator for the seven state Missouri Natural Resources Committee. Dr. Keenlyne received his B.S. degree from the University of Wisconsin and his M.S. degree, M.A. degree, and Ph.D. degree from the University of Minnesota.

Stephen S. Light is the Director of the Environment and Agriculture Program the Institute for Agricultural and Trade Policy in Minneapolis. As a Policy Director with the South Florida Water Management District in the early 1980s, Dr. Light helped introduce adaptive management into the management of the Florida Everglades, and helped develop an iterative testing process for reintroducing flows into the Shark River slough in Everglades National Park. Dr. Light was a co-editor of the widely cited 1995 volume on *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. He received his B.S. degree from Thiel College, his M.S. degree from Penn State University, and his Ph.D. degree in natural resources policy and management from the University of Michigan.

Ernest Smerdon (NAE) is recently retired vice-provost and dean of the College of Engineering and Mines at the University of Arizona. Dr. Smerdon has served as an advisor to the U.S. federal government and several foreign governments on water resources and agricultural development issues for four decades. He has authored over 100 professional papers on water resources planning, engineering, and irrigation. He has also served on several NRC committees and boards. Dr. Smerdon received his B.S. degree, his M.S. degree, and his Ph.D. degree, all in engineering, from the University of Missouri.

A. Dan Tarlock holds an A.B. and LL. B. from Stanford University and is currently Distinguished Professor of Law and Associate Dean for Faculty at the Chicago-Kent College of Law. He has practiced law in San Francisco and Denver and taught at the University of Chicago, Indiana University, the University of Kansas, the University of Michigan, the University of Texas and the University of Utah. He has written and consulted widely in the fields of water law, environmental protection, and natural resources management. From 1987-1994 he was a member of the Water Science and Technology Board. From 1989-1992 he chaired the Committee on Western

Water Management Change, the report of which was published as Water Transfers in the West (1992). In 1997-1998, he served as the principal writer for the Western Policy Advisory Review Commission's report, Water in the West. Professor Tarlock currently serves as one of the three United States legal advisors to the Secretariat of the Commission on Environmental Cooperation, established by the NAFTA Environmental Side Agreement.

Robert Wetzel is a professor of biological sciences at the University of North Carolina at Chapel Hill. His research interests include the physiology and ecology of bacteria, algae, and higher aquatic plants; biogeochemical cycling in fresh waters; and functional roles of organic compounds and detritus in aquatic ecosystems. His professional experiences include positions as a professor at the University of Alabama, Michigan State University, Erlander National Professor of the Institute of Limnology of Uppsala University in Sweden, and a professor at the University of Michigan. Dr. Wetzel is an elected member of the Royal Danish Academy of Sciences and the American Academy of Arts and Sciences. He earned his B.Sc. degree and his M.Sc. degree from the University of Michigan and his Ph.D. degree from the University of California at Davis.

Jeffrey W. Jacobs is a senior program officer at the National Research Council's Water Science and Technology Board. His research interests include organizational and policy arrangements for water resources planning, water resources science and policy relations, and international cooperation in water development. He has studied these issues extensively in Southeast Asia's Mekong River basin and has conducted comparative research between water management issues in the United States and Southeast Asia. He received his Ph.D. degree in geography from the University of Colorado.