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; Holling et al., 1994; Light et al., 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, 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 (Arrow et al., 1995).

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 (Walters, 1974). 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 interest groups (NRC, 1999). 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 counter-productive 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 some 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 river's 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, MRD, Fish and Wildlife Mitigation Plan, 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 underway at nine sites, and acquisition is underway 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 controls 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

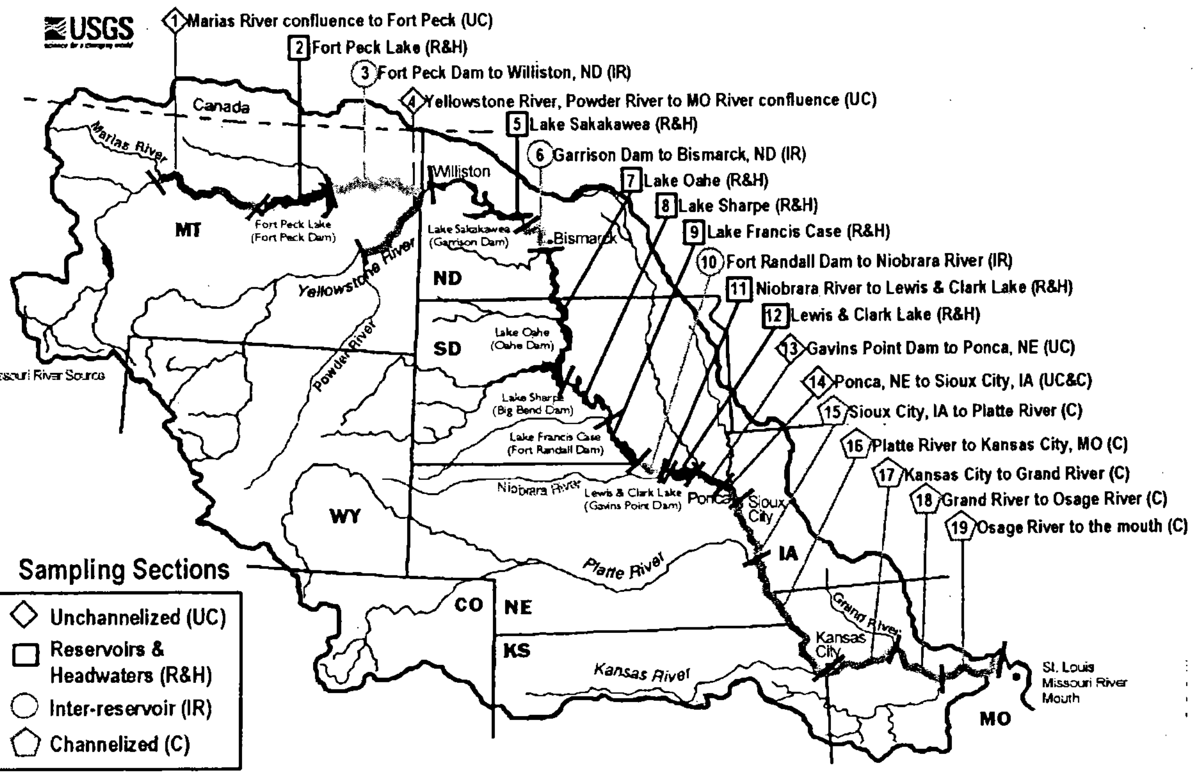

FIGURE 6.1 Missouri River basin and river reaches.
SOURCE: USGS, undated

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

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'."

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. 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, and 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 willing 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 the next upstream segment in the early 1990s. Catfish, the 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. This would result in cut-and-fill 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 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).

Trade-Offs 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 efforts 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, 2000; 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 slowly 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 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 nongovernmental 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 between 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 significant 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 if 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 suffer 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., 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 underway. 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.

The committee believes that 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.

Appendixes

Appendix A

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,chan.border
Brachycercus	Collector-gatherer	Channel,chute,sand

Family Heptageniidae		
Heptagenia	Scraper-collector-gatherer	Chan.border,chute
Pseudiron	Predator-engulfer	Chan.sandbars

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 - Continued.

Taxa	Trophic group	Habitat
Stenonema	Scraper-collector-gatherer	Chute,backup,pools
Stenocron	Scraper-collector-gatherer	Chan.border,chute
Anepeorus	Predator	Chan.chute,borders
Family Leptophlebiidae		
Leptophlebia	Collector-gatherer	Backup,marsh,pool
Paraleptophlebia	Shredder-detritivore	Chan.,chute,backup
Family Siphlonuridae		
Isonychia	Collector	Channel,chan.border
Family Baetidae		
Baetis	Collector-gatherer-scraper	Chan.,chute,sandbar
Pseudocleon	Scrapers	Channel,chute,sandbar

Centroptilum	Collector-gatherer-scraper	Pool,backup,sandbar
Heterocloeon	Scraper	Channel,chan.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

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 - Continued.

Taxa	Trophic group	Habitat
Trichoptera		
Family Hydropsychidae		
Hydropsyche	Collector-filterer	Chute,chan.borders
Potamyia	Collector-filterer	Chute,chan.borders
Cheumatopsyche	Collector-filterer	Chute,chan.borders
Family Polycentropodidae		
Neuroclipsis	Shredder-herbivore	Chute,backup,marsh

Nyctiophylax	Predator-collector-filterer	off chan.habit.
Cyrnellus	Collector-filterer	off chan.habit.
Family Hydroptilidae		
Mayatrichia	Scraper	
Hydroptila	Piercer-herbivore	Backwater borders
Agraylea	Piercer-herbivore	Backwater borders
Family Leptoceridae		
Ceraclea	Collector-gatherer	All aquat.habit.
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

Table 1. Listing of the most numerous aquatic insects collected from the Missouri River in Nebraska using Hester-Dendy artificial samplers, dredges, and plankton nets from 1983 through 1986, and their preferred habitat - Continued.

Taxa	Trophic group	Habitat
Family Brachycentridae		
Brachycentrus	Collector-filterer	Channel,chute
Diptera		

Family Chironomidae	Collector-gatherer-filter	All aquat.habitats
Family Tipulidae	Shredder-detritivore	All aquat.habitats
Family Tephritidae		
Family Tabanidae	Predator	Backup,marsh,puddle
Family Chaobordiae	Predator-engulfer	Backup,marsh,puddle
Family Culicidae	Collector-filterer-gatherer	Backup,marsh,puddle
Family Simuliidae	Collector-filterer	Chute,channel
Family Mycetophilidae		
Family Ceratopogonidae	Predator-gatherer	Backup,marsh,puddle
Family Muscidae	Predator	All aquat.habitats
Family Tachinidae		
Family Stratiomiyidae	Collector-gatherer	Backup,marsh,puddle
Family Agromyzidae		
Family Cecidomyidae		
Family Empididae	Predator	off chan.habitat
Family Sciaridae		
Family Dolichopodidae		

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 - Continued.

Taxa	Trophic group	Habitat

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	Chan.,chute,borders
Odonata		
Family Coenagrionidae		
Argia	Predator	off chan.habitat
Ischnura	Predator	Chute,backup,marsh
Coenagrion	Predator	off chan.habitat
Agrion	Predator	off chan.habitat
Enallagma	Predator	Backup,marsh,puddle

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 - Continued.

Taxa	Trophic group	Habitat
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 chan.habitat
Family Dryopidae	Scraper-collector-gatherer	Chute,chan.,sandbar
Family Curculionidae	Shredder-herbivore	Backup,marsh,puddle
Family Helodidae	Shredder-herbivore	Oxbow,puddle,marsh
Family Hydrophilidae	Predator	All aquatic habitats
Family Staphylinidae	Predator	Sandbar,dune
Family Elmidae	Collector-gatherer-scraper	Chute,chan.,sandbar
Family Heteroceridae	Predator	Sandbar,dune
Family Carabidae	Predator	

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 - Continued.

Taxa	Trophic group	Habitat
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 chan.habitat

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 - Continued.

Taxa	Trophic group	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	
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 referrence.

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.

Table 4. Fish species of the Missouri River and its floodplain with preferred habitat, present status, and distribution and reference (continued).

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

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

Table 4. Fish species of the Missouri River and its floodplain with preferred habitat, present status, and distribution and reference (continued).

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

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

---

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 (from Whitmore and Keenlyne 1990).

Federally listed species are indicated by a *.

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)

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)

References

Ambrose, S. E. 1996. Undaunted Courage. The Wilson Bulletin 100:272–284.

Babbit, B. 1999. Foreword. In: Webb, et al. Editors. The Controlled Flood In Grand Canyon. Washington, D.C.: American Geophysical Union.

Barry, J. M. 1998. Rising Tide: The Great Mississippi Flood of 1927 and How It Changed America. New York, NY: Simon and Schuster.

Benson, N. G. Editor. 1988. The Missouri River: The Resources; Their Uses, and Values. American Fisheries Society, North Central Division, Special Publication No. 8.

Botkin, D. B. 1995. Our Natural History: The lessons of Lewis and Clark. New York, NY: G. Putnam & Sons.

Budiansky, S. 1995. The New Science of Nature Management. New York, NY: Free Press.

Carrels, P. 1999. Uphill Against Water: The Great Dakota Water War. Lincoln, NE: The University of Nebraska Press.

Daily, G. C. Editor. 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Washington, D.C.: Island Press.

DeVoto, B. 1947. Across the Wide Missouri. The American Heritage Library. New York, NY: Houghton Mifflon Company.

Dunbar, R. 1983. Forging New Rights in Western Waters. Lincoln: University of Nebraska Press.

Eubanks, Jr., T. L., Ditton, R. B., and Stoll, J. R. 2001. Platte River Nature Recreation Study: The Economic Impact of Wildlife Watching On the Platte River in Nebraska. [Online]. Available: http://www.fermatainc.com/basic.eco_nebplatte.html [2001, November 29].

Ferrell, J. 1993. Big Dam Era. Omaha, Nebraska: U.S. Army Corps of Engineers, Missouri River Division.

Ferrell, J. 1996. Soundings. Omaha, Nebraska: U.S. Army Corps of Engineers, Missouri River Division.

Gleick, P. H. 2000. The World's Water 2000-2001: The Biennial Report on Freshwater Resources. Washington, D.C.: Island Press.

Government Accounting Office (GAO). 1992. Water Resources: Corps' management of the ongoing drought in the Missouri River basin. GAO/RCED-92-4. Washington, D.C.: U.S. Government Printing Office.

Gunderson, L. H., C. S. Holling, and S. S. Light. 1995. Barriers and Bridges to Renewing Ecosystems and Institutions. New York, NY: Columbia University Press.

Hart, H. C. 1957. The Dark Missouri. Madison, WI.: University of Wisconsin Press.

Hays, S. P. 1999. Conservation and the Gospel of Efficiency. Pittsburgh, PA: University of Pittsburgh Press.

Hesse, L. W., J. C. Schmulbach, J. M. Carr, K. D. Keenlyne, D. G. Unkenholz, J. W. Robinson, and G. E. Mestl. 1989. Missouri River fishery resources in relation to past, present, and future stresses. In: Dodge, D. P., editor. Proceedings of the International Large River Symposium (LARS): Honey Harbour, Ontario, Canada, Septmeber 14-21, 1986. Canadian special publication of fisheries and aquatic sciences no. 106. pages 352-371. Ottawa, Canada: Department of Fisheries and Oceans.

Hirsch, R. M., J. F. Walker, J. C. Day, and R. Kallio. 1990. The influence of man on hydrologic systems. Pages 329–359. In: Wolman, M. G. and H. C. Riggs, editors. The geology of North America, vol. O-1. Surface water hydrology. Boulder, CO: Geological Society of America.

Holling, C. S. 1978. Adaptive environmental assessment and management. London, U.K.: J. Wiley.

Holmes, B. H. 1972. A History of Water Resources Program 1800–1960. Department of Agriculture Misc. Pub. 1233. Washington, D.C.: U.S. Government Printing Office.

Jehl, D. 2000. Indian-Graves Fight Forces Change in Missouri River Power. New York Times, 9 November 2000.

Johnson, W. C. 1998. Adjustments of riparian vegetation to river regulation in the Great Plains, USA. Wetlands 18(4):608–618.

Lawson, M. 1982. Dammed Indians: The Pick–Sloan Plan and the Missouri River Sioux, 1944–1980. Norman: University of Oklahoma Press.

Light, S. S., J. R. Wodraska, and J. Sabina. 1989. The Southern Everglades: The Evolution of Water Management. The National Forum, Winter, Vol. 8.

Light, S. S., L. H. Gunderson, and C. S. Holling. 1995. The Everglades: Evolution of Management in a Turbulent Ecosystem. Pages 104–168. In: Holling, C. S., L. H. Gunderson, and S. S. Light, Editors. Barriers and Bridges to Renewing Ecosystems and Institutions. New York, NY: Columbia University Press.

Light, S. S. 2001. Adaptive Ecosystem Assessment and Management: the Pathe of Last Resort? Chapter 4. In: Jensen, M. Editor. A Guidebook for Integrated Ecological Assessment. New York, NY: Springer-Verlag.

Marshall, H. 1966. Politics and Efficiency in Water Development. In: Kneese, A. V. and S. C. Smith, Editors. Water Resources Research 291. Baltimore, MD: The Johns Hopkins University Press for Resources for the Future.

Minckley, W. L. 1991. Native Fishes of the Grand Canyon Region: An Obituary? Pages 124–177. In: National Research Council. Colorado River Ecology and Dam Management. Washington, D.C.: National Academy Press.

Minckley, W. L. and J. E. Deacon, Editors. 1991. Battle Against Extinction: Native Fish Management in the American West. Tucson: University of Arizona Press.

Missouri River Commission (MRC). 1895. Map of the Missouri River from its mouth to Three-Forks Montana created by Act of Congress July 5, 1884. Washington, D.C.: Missouri River Commission.

National Paddlefish and Sturgeon Steering Committee. 1993. Framework for the management and conservation of paddlefish and sturgeon species in the United States. U.S. Fish and Wildlife Service, Washington, DC.

National Research Council (NRC). 1995. Wetlands: Characteristics and Boundaries. Washington, D.C.: National Academy Press.

National Research Council (NRC). 1996. Upstream: Salmon and Society in the Pacific Northwest. Washington, D.C.: National Academy Press.

National Research Council (NRC). 2001. Inland Navigation System Planning: The Upper Mississippi River–Illinois Waterway. Washington, D.C.: National Academy Press.

Pisani, D. J. 1992. To Reclaim a Divided West: Water, Law, and Public Policy, 1848–1902. Albuquerque: University of New Mexico Press.

Pisani, D. J. 1996. Water, Land, and Law in the West: The limit of Public Policy, 1850-1920. Lawrence, KS.: University Press of Kansas.

Powell, J. W. Lands of the Arid Region of the United States. Washington, D.C.: Government Printing Office.

Ridgeway, M. E. 1955. The Missouri Basin's Pick–Sloan Plan: a case study in congressional policy determination. Illinois Studies in Social Sciences Vol. 35. Urbana: University of Illinois Press.

Rieke, B. and D. Kinney. 1997. Resource Management at the Watershed Level. Boulder, CO.: Natural Resources Law Center.

Schneiders, R. K. 1999. Unruly River: Two Centuries of Change Along the Missouri. Lawrence, Kansas: University Press of Kansas.

Thorson, J. E. 1994. River of Promise, River of Peril: the politics of managing the Missouri River. Lawrence, Kansas: University Press of Kansas.

Trelease, F. 1953. A Federal-State Compact for Missouri Basin Development. Wyoming Law Review 7: 161

Tyler, D. 1992. The Last Water Hole in the West. Niwot, CO.: The University Press of Colorado.

United States Army Corps of Engineers. 1958. Missouri River Main Stem Reservoir System, Allocation of Costs. Omaha: U.S. Army Engineer Division, Missouri River.

United States Army Corps of Engineers. 1979. Missouri River Main Stem Reservoir System Reservoir Regulation Manual (Master Manual). Omaha, NE.: U.S. Army Engineer Division, Missouri River Corps of Engineers.

United States Army Corps of Engineers. 1981. Missouri River bank stabilization and navigation project final feasibility report and final EIS for the fish and wildlife mitigation plan. U.S. Army Corps of Engineers, Missouri River Division, Omaha District, Omaha.

United States Army Corps of Engineers, Northwestern Division, Missouri River Region, Reservoir Control Center, January 2000. Missouri River Main Stem Reservoirs Summary of Actual 1998-1999 Operations.

United States Army Corps of Engineers, Institute for Water Resources, Navigation and Water Resources Applications Division, Alexandria, VA, August 2000. Projected and Actual Traffic on Inland Waterways.

United States Army Corps of Engineers, Northwestern Division, Missouri River Region, August, 2001. Missouri River Environmental Impact Statement, Revised Draft Summary.

United States Geological Survey (USGS). 1999. Ecological status and trends of the Upper Mississippi River system 1998. La Crosse, WI: Upper Midwest Environmental Sciences Center.

United States Water Resources Council (WRC). 1983. Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies. Washington, D.C.: U.S. Government Printing Office.

Webb, W. P. 1931. The Great Plains. Boston: Ginn and Company.

World Commission on Dams (WCD). 2000. Dams and Development: A New Framework for Development. Sterling, VA: Earthscan Publications, Ltd.

Worster, D. 1985. Rivers of Empire. New York, NY: Pantheon Books.