3

Missouri River and Floodplain Ecology

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

Captain William Clark, August 20, 1806

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

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

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

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

THE PRE-REGULATION MISSOURI RIVER

Physical Processes: Hydrology and Geomorphology

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

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

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

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

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

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

The pre-regulation river was characterized by log jams, snags, whirlpools, chutes, bars, cut-off channels, and secondary channels around bars. The main channel typically had a deep thalweg (the deepest part of the river) that contained the faster-moving flow and a shallower section(s) on one or both sides of the channel (Figure 3.1). The cross-sectional shape of the main channel often exhibited a highly nonuniform velocity distribution (Hesse, 1993). The main river channel's width was variable, ranging from roughly 1,000 to 10,000 feet wide during normal flow periods to 25,000 to 35,000 feet wide during floods (Schneiders, 1999). River depth was deepest in spring and early summer and shallowest in December and January. However, there were scour holes downstream of log jams and other obstructions, at bends, or where tributaries entered. Depths in these holes varied from a few inches to more than thirty feet (Schneiders, 1999). Mid-channel and point bars were found along the entire length of the Missouri River. The bars shifted frequently in response to changing flows with the larger bars scoured at higher flows.

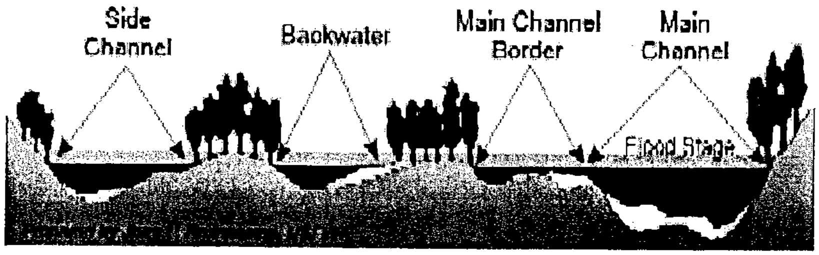


FIGURE 3.1: Pre-Channelized Reaches of the Missouri River
SOURCE: Rasmussen, 199 .

Biological Processes

The rich biodiversity (see Box 3.1) of the pre-regulation Missouri River ecosystem was sustained through a regime of natural disturbances that included periodic floods and attendant sediment erosion and deposition. These disturbances, in turn, supported a variety of ecological benefits, including commercial and recreational fishing, timber, biomass fuels, wild game, trapping and fur production, clean water, medicines, soil replenishment processes, and natural recharge of groundwater. The physical and biological processes associated with periodic flooding in river-floodplain ecosystems is encompassed by the contemporary concept known as "the flood pulse."

The Flood Pulse Concept

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

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

Box 3.1
Biodiversity

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

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

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

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

THE POST-REGULATION MISSOURI RIVER

Physical Processes: Hydrology and Geomorphology

Flow regulation and channelization substantially changed the Missouri River's historic hydrologic and geomorphic regimes. The primary change was that the extreme high and extreme low flows were removed from the hydrograph downstream of each mainstem dam. This dampening effect below Gavins Point Dam extends downstream to near Nebraska City, Nebraska (Hesse, 1994), where tributary influences partially restore pre-regulation flows to the river. Below Fort Peck Dam, for example, the median high flow was cut in half following the dam's closure (Shields et al., 2000). Not only have high flows been markedly reduced in many areas, low flows have increased considerably. The result of these changes is an annual hydrograph that exhibits far less variability. Figures 3.2 and 3.3 show hydrologic changes in the post-regulation river at Sioux City, Iowa (just downstream of Gavins Point Dam) and at Hermann, Missouri. These figures illustrate hydrologic changes with the construction of the mainstem dams. The figures also show that these changes are not uniform along the Missouri River and that some downstream sections in the state of Missouri have experienced less

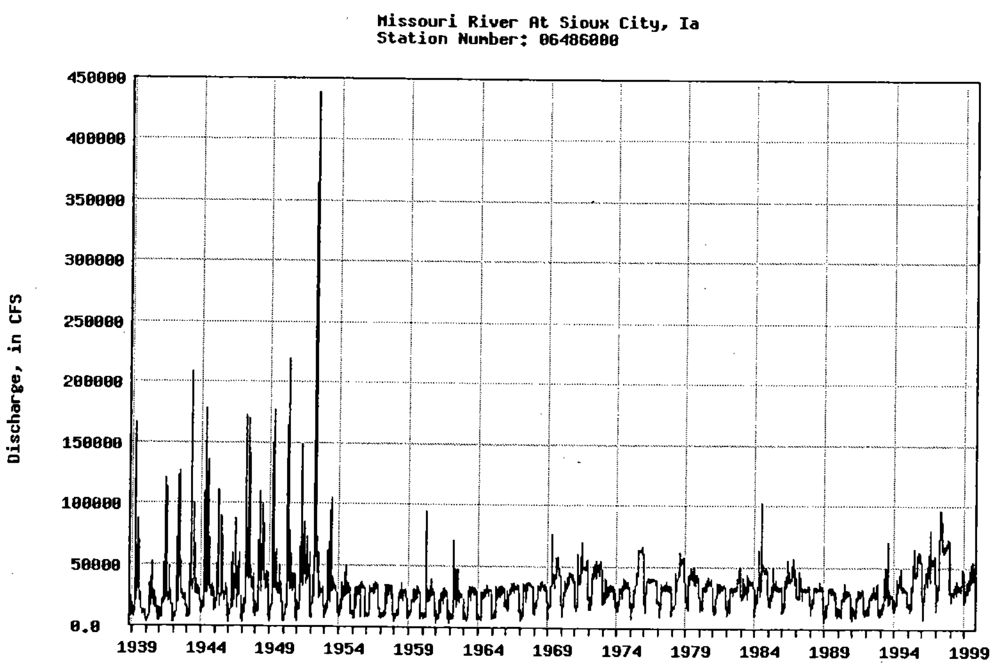


FIGURE 3.2 Missouri River Discharge (cfs) at Sioux City, Iowa
SOURCE: USACE, 199_.

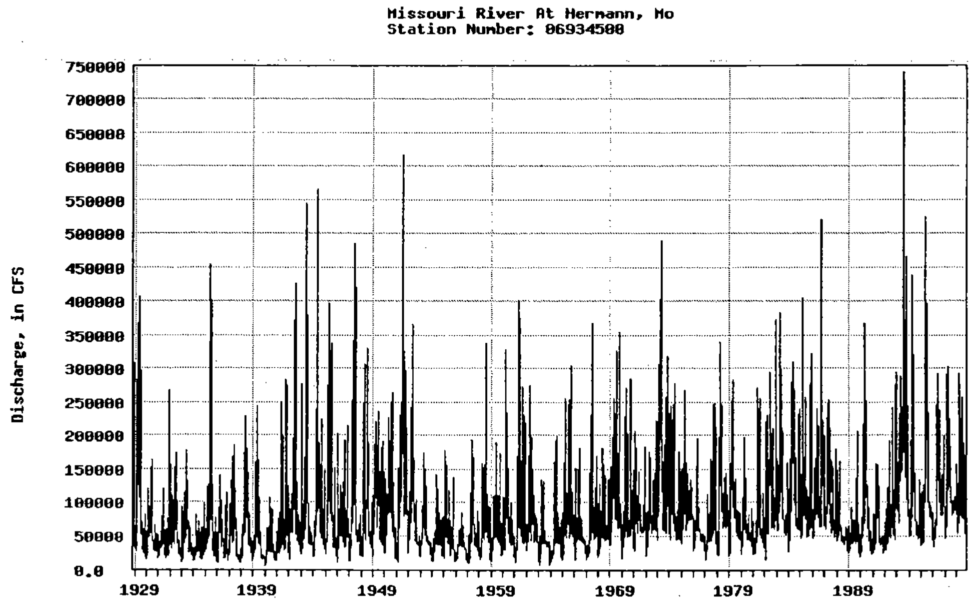


FIGURE 3.3 Missouri River Discharge (cfs) at Hermann, Missouri
SOURCE: USACE, 199_.

hydrologic change with regulation. But the variability that characterized pre-regulation Missouri River hydrology has greatly diminished along most of the river—especially in those reaches directly below the dams—and the spring and summer rises no longer occur in many stretches.

The Missouri River also has experienced large changes to its channel structure and dynamics. The channelized portion of the Missouri River begins near Nebraska's Ponca State Park (just upstream of Sioux City, Iowa). From Ponca State Park downstream to the Big Sioux River, the river channel is stabilized. The navigation channel then begins at the Big Sioux River at Sioux City. The navigation channel, which extends to St. Louis, ranges in width from 600 feet at the Big Sioux confluence to roughly 1100 feet at St. Louis. Nearly all channelization activities have been conducted as part of the federal Missouri River Bank Stabilization and Navigation Project (passed as part of the 1945 Rivers and Harbors Act), which is executed by the Corps of Engineers. Channelization has been accomplished through a combination of engineering structures, including hardpoints, a variety of revetments, dikes, and sills (Slizeski et al., 1982; see Figure 3.4).

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

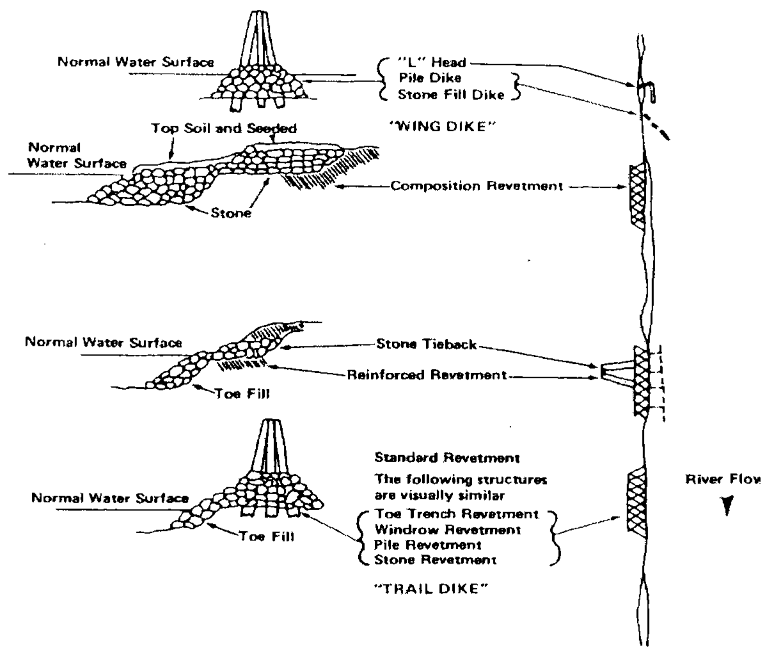


FIGURE 3.4 Commonly used dikes and revetments along the Missouri River navigation channel.
SOURCE: Slizeski et al.,1982.

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

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

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

Channel degradation below the Missouri River's mainstem dams is well documented (Holly and Karim, 1986; Mellema and Wei, 1986; Osterkamp and Hedman, 1982; Sayre and Kennedy, 1978). For example, Figure 3.5 shows that degradation on the order of ten feet or more extends many miles downstream of Garrison Dam. Similarly, below Gavins Point Dam, the river in 1980 had degraded by 8.5 feet.

Degradation of the river channel disconnects the river channel from its floodplain. Channel degradation not only makes it more difficult for the river to overflow its banks, but it also affects the floodplain water table. Most importantly, the lack of flooding removes a source

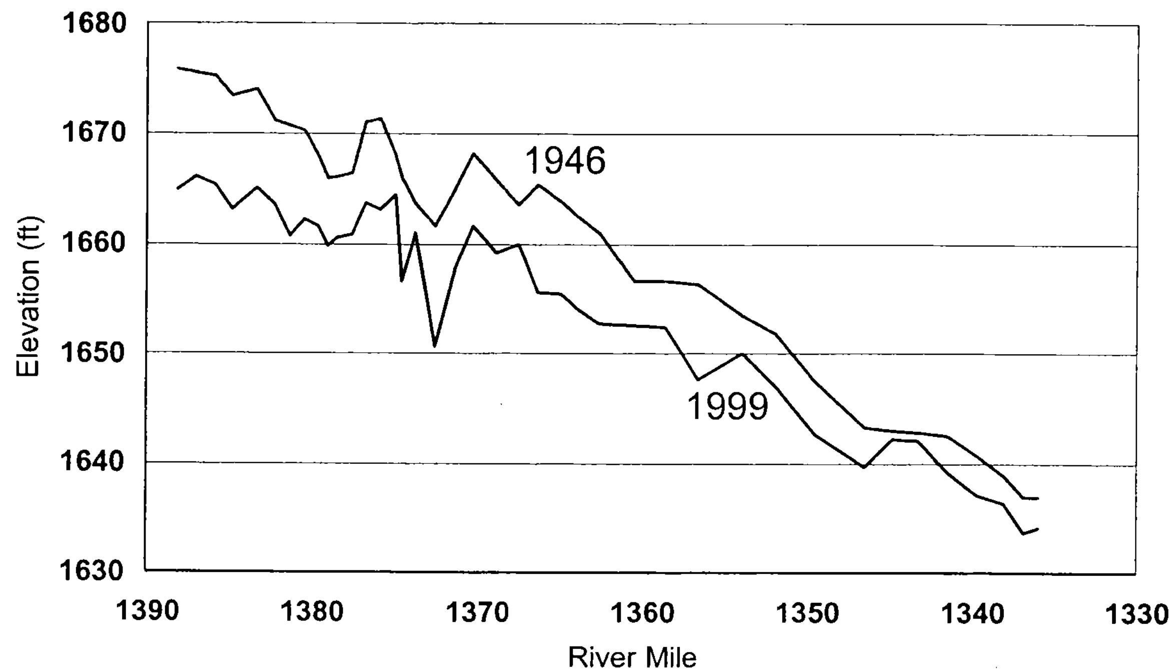


FIGURE 3.5 Average bed elevations below Garrison Dam (located at River Mile 1390) from 1946-1999 (river miles measure distance upstream from the Missouri River's mouth near St. Louis).
SOURCE: USACE 1993; 1999.

of periodic recharge water for infiltration to the groundwater table. In addition, because the water table (an alluvial aquifer) is hydrologically connected to the river channel itself, there is a consequent lowering of this aquifer in association with the lowering (incision) of the river channel. This lowering of the water table effectively drains water from oxbow lakes and wetlands. Moreover, in highly-regulated stretches of the river, reduced fluctuations in river stage have resulted in reduced fluctuations in the floodplain water table. These fluctuations are important to maintaining animal and plant species richness in the floodplain, as some species will benefit from a raised water table, while other species will benefit when the water table is lower.

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

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

Ecological Processes

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

As a result of these changes, the production and the diversity of the ecosystem have both markedly declined. One of these impacts is a reduced ability for trees to regenerate. On the Missouri River and many of its tributaries, this has especially been the case for the cottonwood, largely as a result of the current low rate of river meandering (Johnson et al., 1976; Johnson, 1992). The habitat through a typical cross-section of the post-regulation Missouri (in the non-submerged portions) has been greatly simplified (Figure 3.6). Side channels and backwater areas have been greatly reduced, thereby eliminating important habitat for many species of fishes, birds, and game. The water, sediment, and nutrients previously spread across the floodplain by overbank flows and the meandering river are now primarily restricted to the main channel or contained in the system's reservoirs. These changes, combined with other human activities in floodplain areas, have produced an ecologically impoverished ecosystem.

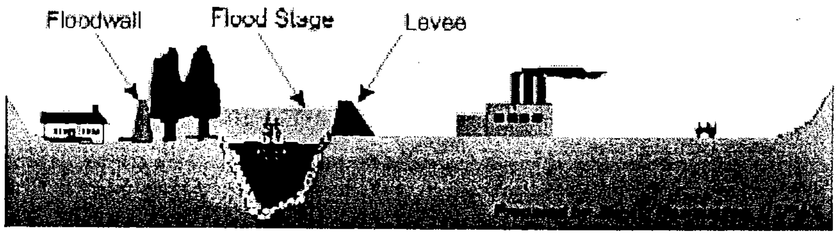


FIGURE 3.6 Typical cross-section of the post-regulation, channelized Missouri River
SOURCE: Rasmussen, 199 .

MISSOURI RIVER ECOSYSTEM PHYSICAL AND ECOLOGICAL UNITS

Scientific investigations today are conducted in an ecosystem that changed greatly during the twentieth century and that today is fragmented into distinct physical and ecological units. The mainstem dams, along with other flood damage reduction and navigation enhancement projects, partition the river into four sub-units that differ greatly in hydrology, sediment balance, and biota (Figure 3.7). The river can be classified into four sub-units:

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

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

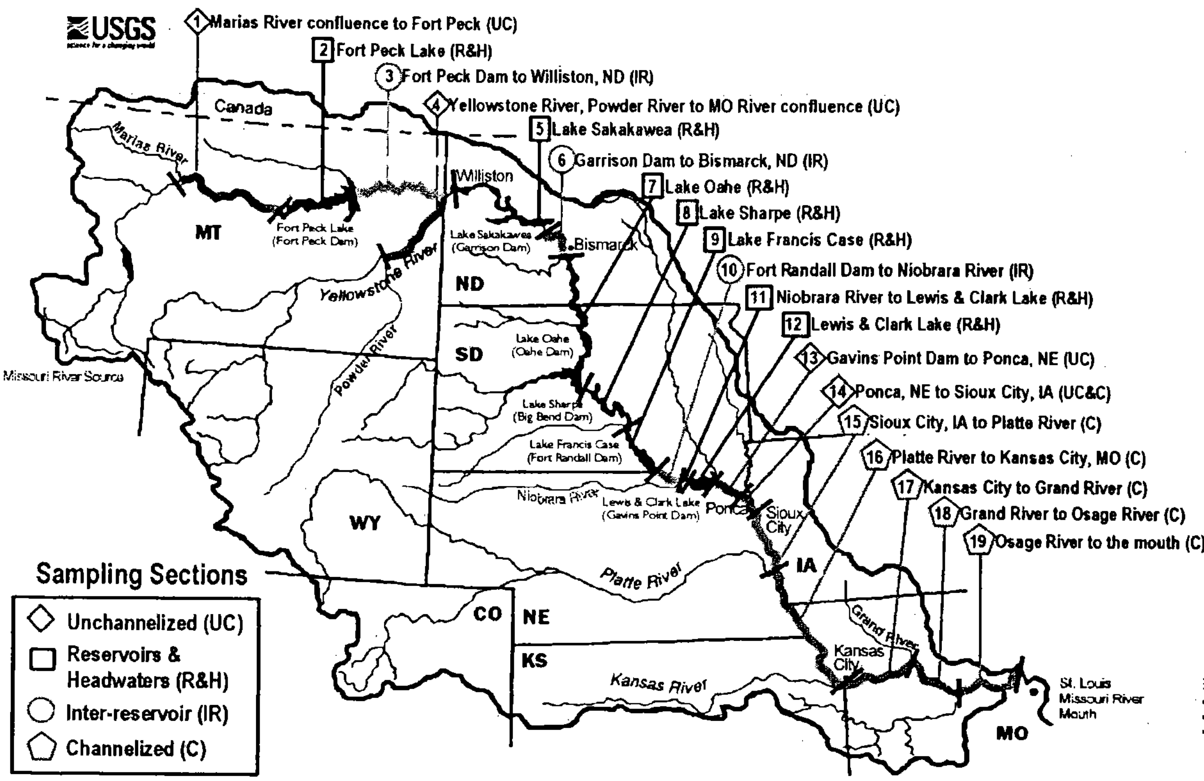


FIGURE 3.7 Missouri River basin and river reaches.
SOURCE: USGS, undated.

Missouri River Tributaries

Yellowstone River

The Yellowstone River flows 675 miles through Montana to its confluence with the Missouri River at the North Dakota border (Figure 3.7). The Yellowstone River is the longest free-flowing river remaining in the contiguous United States. There are no significant impoundments on the Yellowstone's mainstem, but nearly one-third of its drainage area has been dammed and six low-head dams on the main channel divert water for irrigation (Helfrich et al., 1999). While irrigation withdrawals and tributary dams affect the river's hydrology (Zelt et al., 1998) and the low-head dams restrict upstream movement of some native fishes (Helfrich et al., 1999), the river retains much of the ecological character it exhibited prior to European settlement (Jackson, 1994). At their confluence, the Yellowstone River's flow is greater than Missouri River's.

Where the Yellowstone River, with its abundant silt load and naturally varying hydrology, meets the Missouri River near the Montana-North Dakota border, near pre-regulation conditions exist. In fact, the Yellowstone River serves as a refuge for many of the Missouri River's native, warm-water fish (Ryckman, 2000). For example, there are high levels of paddlefish reproduction in the lower Yellowstone in years with above average streamflow. Additionally, native suckers and chubs—in decline throughout much of the river system—are fairly abundant and reproduce in the confluence area (Ryckman, 2000). Moreover, the Missouri

River downstream of the confluence is a healthy riparian zone that includes ample cottonwood and willow generation maintained by floods and sediment contributed by the Yellowstone.

Bad River

The unregulated Bad River empties into the Missouri River at Fort Pierre in central South Dakota just upstream of Lake Sharpe, the smallest of the Missouri River mainstem reservoirs (Figure 3.7). The Bad River is small and intermittent and therefore provides only limited ecological benefits to the Missouri River mainstem when compared to the flows of the Yellowstone River. Moreover, there is only a short distance between the confluence of the Bad and Missouri rivers and Lake Sharpe, leaving little of the sediment-deprived Missouri River downstream of Oahe Dam to benefit from the Bad River's input of sediment-laden water.

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

Platte River

The Platte River enters the Missouri River near Plattsmouth, Nebraska (Figure 3.7). While the Platte's upper tributaries (South and North Platte rivers) are highly regulated and used for irrigation water, the relative lack of storage reservoirs on the Platte River itself allows considerable amounts of sediment to enter the Missouri River at the confluence. Grain sizes of this sediment range from coarse to fine sand. The sizeable increase in the Missouri River's bedload increases the potential for in-channel bar formation and alluviation on the floodplain during floods. The sediment and flow variability added to the Missouri River by the Platte River offer the potential for improving river ecology; but this potential is limited because of the Missouri River's channelized and highly regulated state both above and below its confluence with the Platte.

Kansas River

In contrast to the Bad and Yellowstone rivers, the Kansas River is heavily regulated (Figure 3.7). Eighteen reservoirs, with a total flood-control capacity of 7.4 million acre feet, have been constructed on the Kansas River (Perry, 1993). These reservoirs are intended to reduce flood damages and to enhance navigation flows on the Missouri River. Although the Kansas River is large enough to affect conditions in the Missouri River below the Kansas River's mouth, flow regulation and sediment trapping by its reservoirs reduce the potential of the Kansas River to improve ecological conductors in the Missouri River.

Physical Units of the Regulated Missouri River

Free-Flowing Reaches

The only free-flowing reach of the Missouri River lies in Montana, upstream of the mainstem dams. This reach without reservoirs extends from the Missouri River source near Three Forks, Montana, downstream to Canyon Ferry Reservoir, a distance of about 30 miles. However, the much longer reach from Canyon Ferry Dam to Fort Peck Lake is only mildly regulated because of the comparatively small storage capacity of Canyon Ferry Reservoir relative to total river flow and the long distance between Canyon Ferry Dam and the next downstream reservoir (Fort Peck). Contributions from small mountain streams and springs help retain some of the natural flow and temperature patterns in this reach as well. These moderately regulated reaches have retained their essential pre-regulation including overbank flooding, adequate sediment supply to prevent channel degradation, scattered populations of cottonwood forests similar to those observed by Lewis and Clark, and productive native fisheries (Scott et al., 1997). Floodplain vegetation in these reaches is often impacted less by river regulation than by local land use practices, such as grazing (Auble and Scott, 1998).

Remnant Floodplains

Remnant floodplain sub-units occur between reservoirs (Figure 3.7). The length of these reaches varies considerably. In some cases, the headquarters of the mainstem reservoirs extend nearly to the tailwaters of the next upstream dam; there are few remnant floodplains from Lake Oahe downstream to Fort Randall Dam. In other cases, reservoirs are separated by large stretches of river (e.g., section 3, from Fort Peck Dam downstream to Williston, North Dakota; see Figure 3.7). These latter subunits have retained a natural appearance, with a sinuous channel and a wide floodplain often with oxbow lakes, sand dunes, and interspersed patches of natural forest vegetation and agricultural fields. The natural appearance, however, masks fundamentally altered hydrologic and sediment regimes. Nonetheless, many of these subunits are not physically static, and undergo natural degradation and sedimentation processes as altered by flows and releases from upstream dams and tributary inflows. Many of these segments are now incised, which has caused the loss of adjacent wetlands and secondary channels.

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

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

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

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

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

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

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

Channelized Reach

Downstream of Gavins Point Dam, the Missouri River has been channelized (narrowed and deepened in a relatively fixed position) from Sioux City, Iowa to its mouth to permit navigation by boats and barges, and its banks were stabilized to enhance utilization of the bankline adjacent to the channel (sections 14-19 in Figure 3.7; Schmulbach et al., 1992). In addition, chutes and side channels have been blocked and diverted, converting the once structurally-complex channels and instream islands into a single thread of deep, fast moving water. Levees have been constructed on both banks along much of the lower river to protect crops and settlements behind them; these levees constrain overbank flows to a narrow zone of the floodplain.

This channelized stretch of the river was once highly dynamic:

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

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

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

MISSOURI RIVER ECOSYSTEM SCIENCE

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

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

Research on Fisheries

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

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

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

The Pallid Sturgeon

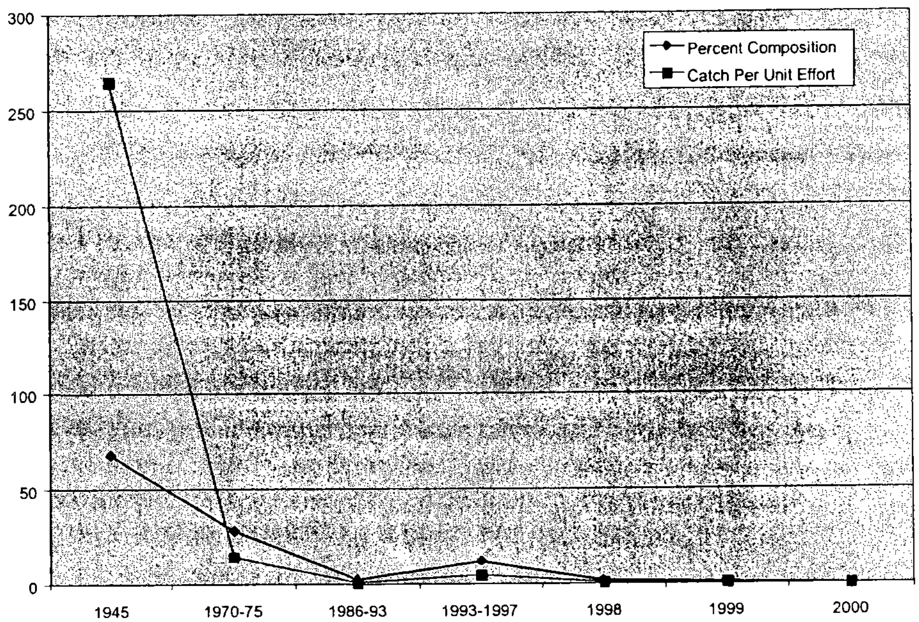
The pallid sturgeon was listed as endangered throughout its entire range on September 6, 1990, and the species is currently considered close to extinction (Dryer and Sandvol, 1993). Pallid sturgeons were thought to live primarily in large, turbid rivers such as the Missouri, and the Mississippi River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

Plains Minnows and Sauger

The plains minnow and the sauger are two examples of common Missouri River native fish species that declined rapidly in the aftermath of dam construction and channelization. Plains minnows were once considered the most abundant minnow in the portion of the Missouri River in upper Missouri (Cross, 1967; Fisher, 1962; Jones, 1963; Morris et al., 1972; Pflieger, 1975). This small minnow was well adapted to the river's turbid environment. It lived among the numerous sandbars, feeding on living and dead plant material, living and dead, and was an important component of the trophic web of the pre-regulation and pre-regulation Missouri River (Hesse, 1994). The plains minnow has experienced a dramatic decline in abundance and is a much smaller component of the species composition today (Figure 3.8). It rebounded for a few years during a wet period between 1993 and 1998, but the increase in abundance was quickly reversed, as floodplain connectivity was severed during 1998 and 1999.

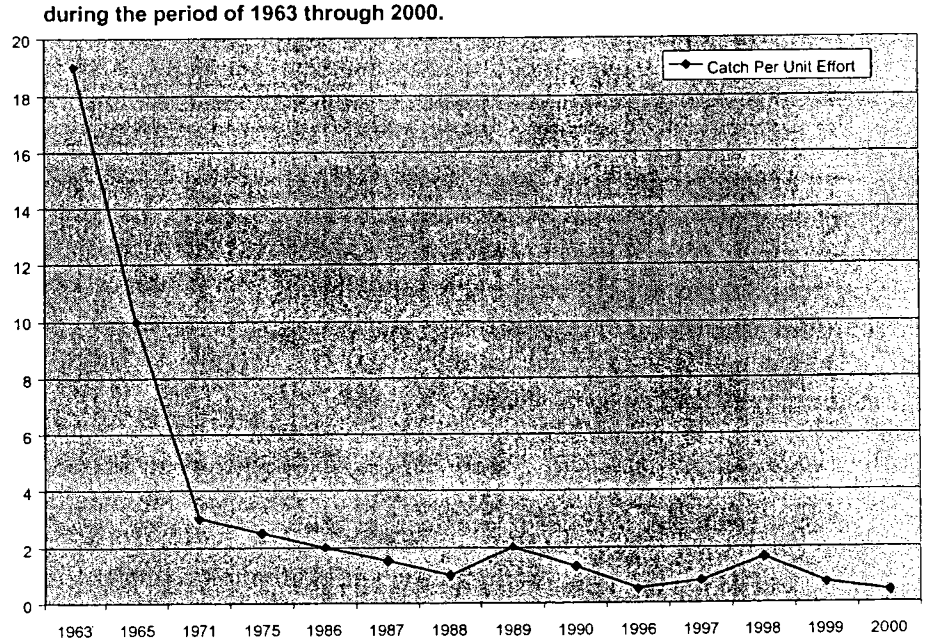
Saugers were common prior to channelization and impoundment of the Missouri River (Cross, 1967; Jones, 1963; Jordan and Evermann, 1969). The species comprised between 10 and 65 percent of the main channel large-river fish assemblage. They have since declined by as much as 98 percent in some locations in the river (Figures 3.8 and 3.9; from Hesse, 1994). Sauger were important sport fish of exceptional food quality, and recreational anglers fished for sauger before the mainstem dams were built. They are closely related to the walleye except they were widely adapted to the turbid environment of the Missouri River, which meant they were much more numerous than walleye before river regulation .

Figure 3.8. Percent composition and catch per unit effort of plains minnow (*Hybognathus placitus*) in seine hauls of equalized effort from sites adjacent to Nebraska, Iowa, and Missouri for periods between 1945 and 2000.



SOURCE: Hesse, 1994.

Figure 3.9 Catch per unit effort of sauger (*Stizostedion canadense*) by standardized electrofishing from channelized sites an the Missouri River adjacent to Nebraska and Iowa during the period of 1963 through 2000.



SOURCE: Hesse, 1994.

The list of threatened or endangered Missouri River species continues to grow. Whitmore and Keenlyne (1990) noted that 82 species found along the Missouri River were listed as rare, threatened, or endangered by the seven states bordering the river. 24 fish, 22 birds, 14 plants, 8 reptiles, 6 mammals, 6 insects, and 2 freshwater mussels were included (Appendix B lists threatened and endangered species along the Missouri River).

Research on Floodplain Vegetation

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

COMMITTEE COMMENTARY

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

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

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

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

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

4

Values of the Missouri River System and Operations

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

The President's Water Resources Policy Commission, 1950

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

ECONOMIC AND SOCIAL FEATURES IN THE MISSOURI BASIN

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

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

The most striking demographic feature of the basin is the twentieth-century exodus from rural to urban areas. Populations are declining in much of the region, in some cases dramatically (Figure 4.1). During the 1990s, eastern Montana, for example, experienced a net population loss. Small net population gains in the Dakotas mask the fact that nearly all the population growth has been in the states' cities; most rural areas are experiencing population declines. Many areas in the upper basin are populated by fewer than six people per square mile. North Dakota's and South Dakota's 1990-2000 population gains were among the smaller in the nation and eastern Montana experienced a net population loss. Population densities decrease as one moves upstream along the Missouri River. Montana, North and South Dakota, and Wyoming are the four least densely populated states in the contiguous United States. North Dakota's population growth of 0.5 percent in the 1990s was the lowest of any U.S. state (http://www.census.gov).

(Cut and paste)

SOURCE, U.S. Census Bureau

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

ECONOMIC OUTCOMES OF PICK–SLOAN

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

Projected water project costs and benefits are calculated through formal benefit–cost analysis. The U.S. Army Corps of Engineers has been charged with calculating these costs since the 1936 Flood Control Act. Benefit–cost analysis has evolved from calculating the more obvious costs and benefits of dams and large water projects, to more subtle calculations, such as the benefits of outdoor recreation and the flows of ecosystem benefits produced by aquatic ecosystem restoration. Benefit–cost analysis has a history of classifying difficult-to-measure benefits and costs as "intangible," "noneconomic," or "immeasurable." However, this practice may not have promoted sound decisions, because things beyond the boundary of quantification tend to be ignored or undervalued. Fortunately, methods and procedures for quantifying the difficult to quantify are becoming more easily available (cf. U.S. WRC, 1983; NOAA Panel on Contingent Valuation. *Federal Register* **1993**, *58*, 4601–4614; Daily et al., 2000).

Project Outputs and Benefits

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

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

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

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

Navigation

The most controversial benefit calculation in the Missouri River dam and reservoir system is the value of lower basin navigation enhancement activities. This issue dates back to the first decade following passage of the Pick–Sloan Plan. Writing in 1965, a Stanford University political scientist reported that the 1953 Missouri River Basin Survey Commission "in reviewing the Corps' navigation program on the Missouri could only find one-twelfth of benefits from erosion control and one-third of the savings to shippers claimed by the Corps. The Commission's benefit-cost ratio was half that calculated by the Corps" (Marshall, 1966). Figure 4.2 shows the tonnage carried by navigation on the Missouri from 1960 until the present. In discussing navigation traffic on the Missouri, it is necessary to separate commercial traffic (e.g., corn, soybeans, fertilizers) from the movement of sand and gravel from commercial mining operations, and from the movement of waterway materials connected with construction and maintenance of the navigation channel. Commercial traffic peaked in 1977 at 3.3 million tons or 1.5 billion ton-miles. By 1997, it had dropped to 1.6 million tons or 0.7 billion ton-miles, a fairly steady decline interrupted only by recession or drought years and subsequent recoveries (USACE, 2000a). By the 1990s, commercial traffic had leveled off to an average of 1.5 million tons (0.65 billion ton-miles)

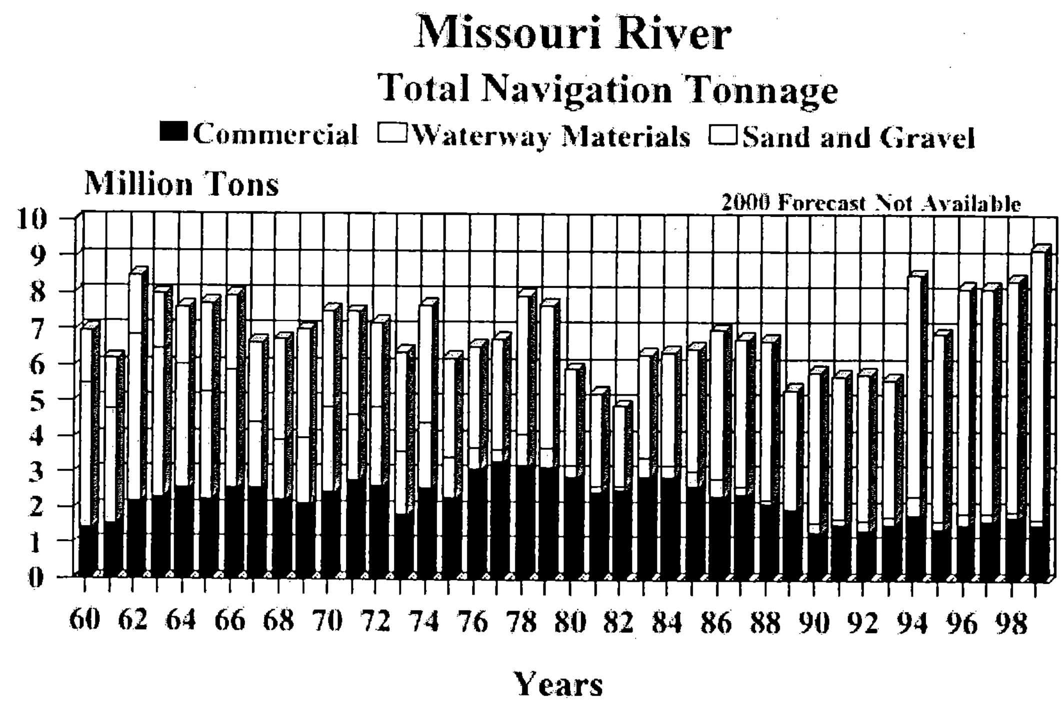


FIGURE 4.2 Total tonnage transported on the Missouri River, 1960—1999.
SOURCE: USACE, 2000a.

Commercial traffic levels on the Missouri have fallen short of the Corps' 1950 projections. The shortfall has been largely because of agricultural grain, food, and food product tonnage failing to meet expectations. After peaking in the 1970s, agricultural tonnage has been in steady decline. The reasons include the development of low-cost unit train traffic to high capacity ports in the Pacific Northwest, the decline in agricultural exports in the 1980s, and the growth of local consumption of products for feed and processing. The drought of the late 1980s and early 1990s also depressed agricultural traffic (USACE, 2000a). Baumel (1998) noted that downstream corn and soybean shipments are "back hauls" that take advantage of empty barges that have transported fertilizer upstream. Without the empty barges already being upriver, corn and soybean shipments would not be economically viable (Baumel, 1998). In 1998, fertilizer, other chemicals, and primary manufacturing goods comprised 42.8 percent of total tonnage while agricultural products comprised 40.6 percent of total tonnage (USACE, 2000a). The Missouri River basin is in an unfavorable competitive position for reaching export markets compared to other regions. Because in the United States, waterborne agricultural shipments primarily serve export markets, this unfavorable competitive position "likely will continue to constrain Missouri River navigation tonnage" (USACE 2000a).

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

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

Net Benefits of Commercial Navigation

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

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

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

Dam (Hesse, 1994). Thus, even if navigation were significantly reduced on the stretch between Sioux City, Iowa and Nebraska City, and there were subsequent changes in flows out of Gavins Point Dam, there would be negligible hydrologic effects on Missouri River navigation downstream of Omaha. The next segment to be examined in sequence would be from Omaha downstream to some point below Omaha. In proceeding segment by segment, the analysis should discover a point at which it is beneficial to retain navigation to the mouth of the river.

Water Supply Benefits

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

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

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

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

Minimum daily flows also help to meet water-quality objectives in the channel, although the mainstem reservoirs seem to present the most frequent water-quality problems. Lake Sakakawea has experienced algal blooms, and other mainstem reservoirs have exceeded state or U.S. Environmental Protection Agency ambient water-quality in the reservoir or in reservoir outflow for a variety of constituents like iron, manganese, agricultural chemicals, and arsenic (USACE, 2000a). Minimum daily flows are also important for meeting ambient water temperature standards below the thermoelectric power plants.

Box 4.1
Irrigated Agriculture

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

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

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

Recreation

Although they did not represent prominent benefits when the Pick–Sloan projects were constructed, water-based recreational uses and benefits have grown substantially along the Missouri River, especially in the upper basin. Figure 4.3 shows that recreation on the reservoir increased from 5 million visitor hours each year in the mid-1950s to over 60 million visitor hours in 1998–2001. Except for setbacks in periods of drought or recession, the annual growth of visitor hours on the reservoir has been remarkably steady. A slackening in the trend is not yet apparent, although there may be different trends in different reservoirs. Visitation has leveled off 1997. No annual statistics are systematically compiled for recreation in the mainstem channel.

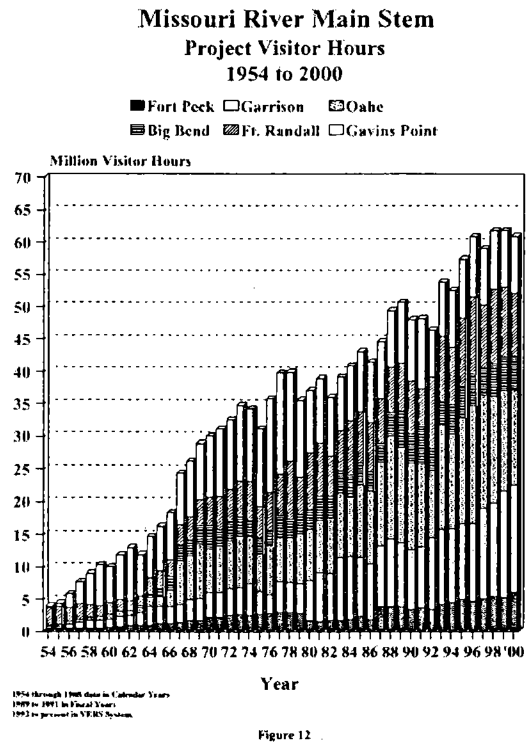


FIGURE 4.3 Recreational use of reservoirs in the Missouri River basin, 1954–2000.
SOURCE: USACE, 2000a.

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

Hydroelectric Power Production

All generating units had been installed and all reservoirs had reached operating levels in the Missouri River mainstem dams by 1967. Since then, power generation has fluctuated with water available. In 1998, power generation was 10 billion kilowatt-hours. This was 99 percent of the average annual production. In 1993, at the end of a drought, power generation was only half as much (USACE, 2000a). Figure 4.4 shows the record of hydropower generation from 1954 to 2000. The value of the hydropower produced is not maximized because releases through the powerhouses or from the dams must satisfy other project purposes like flood damage reduction, navigation, and certain environmental objectives such as tern and plover nesting and

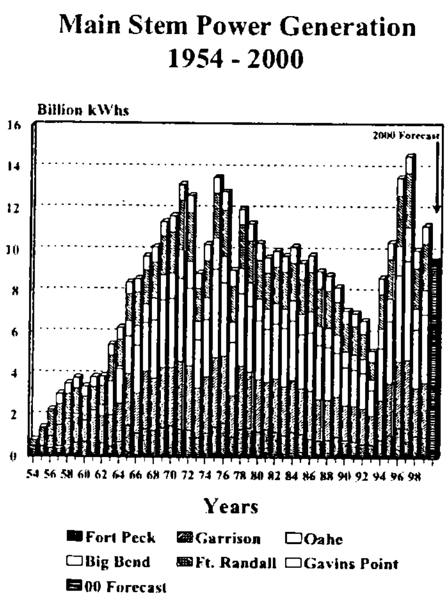


FIGURE 4.4 Hydropower generation in the Missouri River basin, 1954–2000. SOURCE: USACE, 2000a.

recreational use of the river below the dams.

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

The Corps states that of all the project purposes that justify the Missouri River system, hydropower provides the largest national economic benefit, with an annualized value that was no less than $615 million in the Corps' study of operating alternatives (USACE, 1994). Larger values were obtained when flows were modified for the environmental alternatives. Hydropower benefits accrue principally to municipalities (35.7 percent) and to rural electric cooperatives (40.7 percent). In the regional economic allocation, the principal benefiting states are Nebraska (27.3 percent), Minnesota (21.1 percent), and South Dakota (18.6 percent). North Dakota, Iowa, and Montana share the remaining third of benefits (USACE, 1998). Existing hydropower facilities provide an average of 9.5 million megawatt-hours, or about 9 percent of the energy used in WAPA's Mid-Continent Area Power Pool. The six dams in the system—from Fort Peck to Gavins Point—harness 764 of the 1,090 feet of fall from the pool of Fort Peck to the tailwaters of Gavins Point. Nearly all of the water that flows into the Missouri River is used for power generation because flood storage is rarely spilled, and the irrigation withdrawals for the federal projects at Garrison and Oahe, which were expected to divert 3.8 million acre-feet annually, have not materialized. Irrigation developments on the tributaries were expected to divert an additional 2.5 million acre-feet annually but hardly more than 10 percent of these plans have been developed. Only at Gavins Point Dam do inflows exceed the discharge capacity of the powerhouse on a regular basis (i.e., 25 percent of the time).

Flood Damage Reduction

Figure 4.5 shows that cumulative flood damage prevented, as calculated by the Corps, rose rapidly in the 1990s. The years from 1986 to 1997 (inclusive) contained five years of annual runoff that exceeded 90 percent of the years in the historic record of runoff at Sioux City extending back to 1898. Whether hydrology is changing, channel geometry has altered, floodplain storage has diminished, or floodplain investment is increasing substantially—all of which are credible hypotheses—the cumulative record of flood damage prevented shows that by 1975, $1 billion in damages had been prevented; by 1998, this number had increased to $18 billion (in nominal dollars; USACE, 2000a).

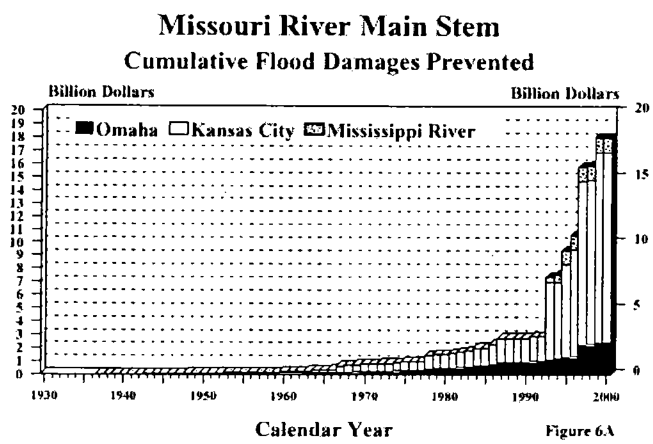


FIGURE 4.5
SOURCE: USACE, 2000a.

Flood damage reduction benefits are based upon a simulation of 100 years of hydrologic data, in which damage without the flood damage reduction features of the Missouri River mainstem dams are estimated. It is presumed that beneficiaries would pay at most this amount to avoid flood damage. Floodplain property values were current when then 1998 study was published. Urban property (not including land) valued at $17 billion and crops valued at $402 million were exposed to flood damage in a 500+ year flood along the Missouri from Fort Peck Dam to the mouth. The Corps estimates that with existing flood storage capacity in place, the current water-control plan annually prevents an average of $414 million in damage. Flood damage reduction benefits for the various sections are as follows: crops, 17.7 percent; residential, 25.8 percent; commercial/industrial, 35.25 percent; and roads/railways, 20.6 percent. The principal states benefiting from the annual benefits of 414 million are Missouri (25.4 percent), Iowa (24.8 percent), Nebraska (18.7 percent), and North Dakota (17.5 percent). Average annual benefits were reduced by about one percent for the environmental options that the Corps studied.

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

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

ACCOUNTING FOR ECOLOGICAL BENEFITS

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

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

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

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

The tourism industry is a significant and growing economic sector in many Missouri basin states and there is evidence that there is a sizable, unmet demand for outdoor recreation activities. For example, thousands of birders travel to the Platte River each spring to witness the annual migration of Sandhill Cranes. The birders' total gross economic output has been estimated in the tens of millions of dollars (Eubanks, Jr. et al., 2001). Trends in the demand for ecosystem-based recreation in the Missouri River basin are upward in nearly all cases. State agencies along the river, such as Nebraska's Papio-Missouri River Natural Resources District, are promoting recreational uses. In Missouri, citizen groups such as the Friends of the Big Muddy and the Missouri River Communities Network promote public participation in improving recreational opportunities in the Missouri River floodplain. These changes are consistent with national trends of increasing demands for and expenditures upon recreational opportunities.

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

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

Box 4.2
Secondary Benefits

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

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

TRADEOFFS AND CONSTRAINTS

Ecosystem Goods and Services

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

Current Operations

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

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

Prospective Tradeoffs and Constraints

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

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

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

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

COMMITTEE COMMENTARY

Sizeable national benefits have been produced by the federal investment in the Missouri River Pick–Sloan Plan. This said, the smallest benefits among the authorized purposes along the mainstem come from irrigation and navigation. Although the annual national benefits from navigation appear to exceed the national costs of maintaining the channel, the expectation that the Missouri River would carry large and growing tonnages of agricultural products to market has not been realized. The reasons for this lie within the competitive disadvantage that the Missouri River basin faces in reaching agricultural export markets. This geographic reality could eventually mean that the cost of channel maintenance could exceed navigation benefits, at least in some upper segments of the channel. Navigation economics are particularly vulnerable to the charge that they ignore the opportunity costs in terms of ecosystem services forgone both in the upstream reservoirs and in the downstream navigation channel. An opportunity cost on the order of $3 million in annual ecosystem benefits foregone would be sufficient to push navigation into the negative range of net national economic development (NED) benefits.

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

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