After the Flood:
Long-Term Restoration of the Lower Missouri River

by

Debra A. Edelstein

A.B., English
Bryn Mawr College, 1974

Submitted to the Department of Urban Studies and Planning
in Partial Fulfillment of the Requirements for the Degree of

Master of City Planning

at the

Massachusetts Institute of Technology

September 1997

Signature of Author: ______________________________
Department of Urban Studies and Planning
July 8, 1997

Certified by: ______________________________
Kristina Hill
Assistant Professor of Urban Studies and Planning
Supervisor

Accepted by: ______________________________
J. Mark Schuster
Associate Professor of Urban Studies and Planning
Chair, MCP Committee

After the Flood:
Long-Term Restoration of the Lower Missouri River

by

Debra A. Edelstein

Submitted to the Department of Urban Studies and Planning
on July 8, 1997, in Partial Fulfillment of the
Requirements for the Degree of Master of City Planning

ABSTRACT

The gorgeous river that Lewis and Clark charted during their myth-making expedition of 1804–6 now runs free in only the first 25 of its 2,315 miles. Large-scale dam, reservoir, and channelization projects have radically altered the morphology, hydrology, and ecology of the river and its floodplain, while making possible the myriad activities upon which human society depends. In the two centuries since European settlement, we have managed the river for the needs of an increasing human population, and in the process have managed to jeopardize the health of the river itself.

The grand engineering projects and the changes in land use they engendered are causing numerous problems. Habitat losses have imperiled many species of plants, birds, animals, and fish. As the Great Flood of 1993 demonstrated, the engineered system no longer serves one of its primary purposes—flood control—and may indeed be exacerbating both floods and droughts. Even under normal climatic conditions there are disputes about controlling the water level in the system to protect either irrigation or navigation, and management decisions pit upstream and downstream users against each other in court battles over whose rights take precedence.

The catastrophic flood and the lessons it offers provide an opportunity to rethink our "control" of the Missouri River and to consider restoring the reach below the last dam, the lower Missouri, to a "natural" state. This thesis examines what a "natural" river might look like and what a restoration could accomplish in such a highly degraded system. It addresses the problems of planning for the changes in and the unpredictable behavior of a newly freed river. Finally, it discusses how, in the context of a restoration that might take half a century or more, we could set priorities, define targets, and manage the human claims to property and protection.

Thesis Supervisor: Kristina Hill
Title: Assistant Professor of Urban Studies and Planning

CONTENTS

Acknowledgments

I want to thank an unusually supportive committee, who patiently waited while I drifted in the wake of family storms and who quietly acknowledged that I know more than circumstances allowed me to write. It's been a pleasure to work with Kristina Hill and with Michael Binford of Harvard University's Graduate School of Design. I also offer thanks to Sam Bass Warner, Jr., for his gracious help in a pinch.

No one who does research at MIT could make much progress without the help of librarians. The staff of Rotch Library in the School of Architecture and Planning and of the interlibrary loan department in Dewey Library cheerfully tracked down materials hidden in our dispersed system and scattered across the continent. I am grateful as well to the staff of the Geography and Map section of the Library of Congress, who, between government shutdowns in 1996, ended my frustrating search for the 1878–92 survey of the entire Missouri River by sending me a copy of the beautiful hand-drawn maps.

This project has also taught me to appreciate the kindness of strangers. When I arrived unannounced at the Missouri Department of Conservation in Jefferson City, intending merely to make appointments, I was treated to informative, on-the-spot interviews and hard-to-find publications. One staff member even offered me a place to stay that night, and another said that if the weather cleared, he could perhaps arrange to fly me over the river with a group of scientists (alas, the clouds and rain persisted). I received an equally helpful reception from Roger Pryor of the Missouri Coalition for the Environment and from staff of the US Army Corps of Engineers, who answered all my questions and sent me the Corps' voluminous post-flood assessments. Let these examples serve as thanks to all who shared their time and expertise.

Finally, I give my deepest thanks to the wonderful friends who kept me afloat in rough waters and proffer lifelong friendship to the sweet sailor who generously taught me how to breathe and swim again.

INTRODUCTION

The gorgeous river that Lewis and Clark charted during their myth-making expedition of 1804–6 now runs free in only the first 25 of its 2,315 miles. Large-scale engineering projects have harnessed the Missouri River, radically altering its morphology, hydrology, and ecology, while making possible the myriad activities upon which human society depends. In the two centuries since European settlement, we have managed the river for the needs of an increasing human population, and in the process have managed to jeopardize the health of the river itself.

The grand engineering works and the changes in land use they engendered are causing numerous problems. In the upper basin, huge dams and reservoirs impound the river and have inundated vast amounts of floodplain land. In the lower basin, wing dikes, revetments, and levees confine the once meandering, braided river to a narrow navigation channel and encourage settlement in and cultivation of bottomlands. Agriculture, the dominant activity in the basin, consumes 83 percent of a floodplain once characterized by grasslands, deciduous forests, and wetlands. The natural riparian forest system, which had occupied over three-quarters of the floodplain, has been reduced to what one federal report describes as "a discontinuous, single row of trees" (Galloway 1994, 55). The combined result of these alterations is a severe disruption of natural hydrologic processes and a critical loss of habitat for many plant, animal, fish, and bird species in the Missouri River basin.

As the Great Flood of 1993 demonstrated, the manmade system also poses threats to the human endeavors it is designed to protect. It no longer serves one of its primary purposes—flood control—and, while promoting settlement in high-risk areas, may even be exacerbating flood levels and damages. Even under normal climatic conditions there are disputes about controlling the water level in the system to protect either irrigation or navigation, and management decisions pit upstream and downstream users against each other in court battles over whose rights take precedence. At issue as well are tribal rights to water resources, pollution of urban drinking water systems, and increased harnessing of the river for hydroelectric power.

The 1993 flood and the lessons it offers provide an opportunity to rethink our "control" of the Missouri River. The federal response to the disaster is a set of general recommendations to move people off the floodplain, reform the National Flood Insurance Program to discourage construction in flood-hazard areas, reevaluate the agricultural levee system, and restore wetlands to provide increased rainwater storage. Those recommendations are guiding the actions of federal, state, and local agencies, which have already purchased lands from farmers and even entire towns that wish to move off the floodplain. But risk reduction through moving selected populations is not a sufficient long-term strategy: it addresses only one consequence—flood damage—and few of the underlying causes of the catastrophe. Opportunistic and piecemeal land acquisitions and wetland restorations may achieve interim objectives, but they do not address the central problem: systemic failure.

Needed instead is a plan that steps back from the short-term political constraints of willing sellers and vested interests and grapples with a more comprehensive restoration of the hydrology of the Missouri River. An ideal plan would encompass the entire river and its watershed, including the major tributaries. Given such an enormous and highly regulated system, however, that would be both politically impractical and logistically impossible. The upstream dams and reservoirs are not coming down, because at least for now the human population depends on the electricity, irrigation, and recreation they provide. But the navigation channel in the lower basin has by some accounts outlived its usefulness, and many residents of the reach below the last dam, weary from battling a series of severe floods, are ready to reenvision the river.

This thesis examines what is perhaps the most ambitious vision: reconnecting the lower Missouri to its floodplain by strategically undoing the engineered system, setting the river free, and allowing natural processes to reassert themselves and do the work of river and ecosystem restoration. I argue that only by relaxing our grasp on the river can we escape the spiralling destruction and regain anything resembling natural function. Resetting the system will require a long-term, coordinated commitment. It entails removing the structural restraints and pushing human activity away from the river's edge. More difficult, perhaps, is that it also requires a fundamental shift in attitude, from seeking to control the river to accepting its inherent unpredictability.

In the following chapters I first briefly examine the engineered system and the attitudes and policies that have made it such an attractive, and intractable, solution to the problems a big river presents. Next I look at the effects of man's intervention, as a way to begin addressing the question of what a restoration could accomplish in such a highly degraded system. My proposal then focuses on what a "natural" Missouri River might look like and discusses planning for the changes in and dynamic behavior of the newly freed river. I attempt as well to link the hydrological restoration to a recovery of ecosystem function. Finally, I discuss how, in the context of a restoration that might take half a century or more, we could set priorities, define targets, and manage the human claims to property and protection.

"Tamed, this river will benefit millions; untamed, it will continue a course which often becomes catastophic. Its vagaries, once accepted as inevitable, must now give way to civilized behavior."

Bureau of Reclamation, *Putting the Missouri to Work*, 1945

1 CIVILIZED BEHAVIOR

From the time Thomas Jefferson acquired it for the nation in the Louisiana Purchase of 1803, the Missouri River has inspired grand plans. A week after he requested appropriations to buy New Orleans from the French, Jefferson submitted to Congress his request for 2,500 dollars to fund an expedition up the Missouri River with "the purpose of extending the external commerce of the U.S."[1] When Meriwether Lewis embarked on the first leg of his journey seven months later, however, he was no longer headed into foreign territory but was charting newly acquired lands that doubled the size of the United States. Jefferson's original intention of monopolizing the fur trade became a vision of nation building through navigation and commerce: he wanted a water route to the West that might tie the frontier territories to the rest of the country and prevent their secession, and he wanted to draw the definitive map of a nation that would control the commerce of a continent.[2]

What the explorers led by Lewis and his partner William Clark traced was a vast river stretching approximately 2,500 miles[3] from its junction with

---

[1]Quoted in Stephen E. Ambrose, *Undaunted Courage: Meriwether Lewis, Thomas Jefferson, and the Opening of the American West* (New York: Simon & Schuster, 1996), 78.

[2]For a discussion of the politics of the acquisition and a history of previous attempts to explore the territory, see Ambrose, *Undaunted Courage*, 51–58, 68–79, and Bernard DeVoto's "Introduction" to his one-volume edition, *The Journals of Lewis and Clark* (New York: Houghton Mifflin Company, 1953).

[3]It is difficult to pin down the official length of the Missouri River. The US Geological Survey variously reports it as "the longest river in the United States," with a length of 2,315 miles, in William H. Langer, Constance K. Throckmorton, and Steve P. Schilling, "Earth Science Issues in the Missouri River Basin—Man's Adaptation to the Changing Landscape," US Geological Survey, Open-File Report 94-195, 1994, 9; and as almost 2,540 miles in US Geological Survey, *National Water Summary 1985* (1986), 506. The Corps of Engineers (Corps 1995b, A, 2) concurs with "at 2,315 miles (1960 mileage), it is the longest river in the United States," although at that length it is 35 miles shorter than the Mississippi as reported by the Corps (Corps 1995a, MR, 1-1). And no one says if the length given is pre- or post-channelization, which shortened

the Mississippi River fifteen miles above St. Louis to its source near what is now Three Forks, Montana. In their journey across the territory, they climbed steadily through the humid lowlands, into the arid Great Plains, and finally across the tundra and montane forest along the Continental Divide (figures 1, 2). By the time they saw the Rocky Mountains, and the end of the dream of a through waterway, they had recorded the latitude and longitude of major geophysical features and the flora and fauna of places previously unseen by white men.

The Rocky Mountains proved not to be the only barrier to a "direct & practicable water communication across this continent."[4] The Missouri River itself—shallow, swift, and filled with snags and shifting sandbars—was a formidable obstacle; and the journals of Lewis and Clark are filled with tales of needing to portage, pole, or masterfully pilot around the danger spots. The vision of a commercial waterway endured, however, and fur-trading companies began moving their wares by steamboat in 1819.[5] They quickly learned it was no easy haul, for as one author noted:

> The Missouri River steamboat should be shallow, lithe, deep-chested, and exceedingly strong in the stern wheel. It should be hinged in the middle and should be fitted with a suction dredge so that when it cannot climb over a sandbar it can assimilate it. The Missouri River steamboat should be able to make use of a channel, but should not have to depend on it. A steamer that cannot on occasion, climb a steep clay bank, go across a corn field, and corner a river that is trying to get away, has little excuse for trying to navigate the Missouri.[6]

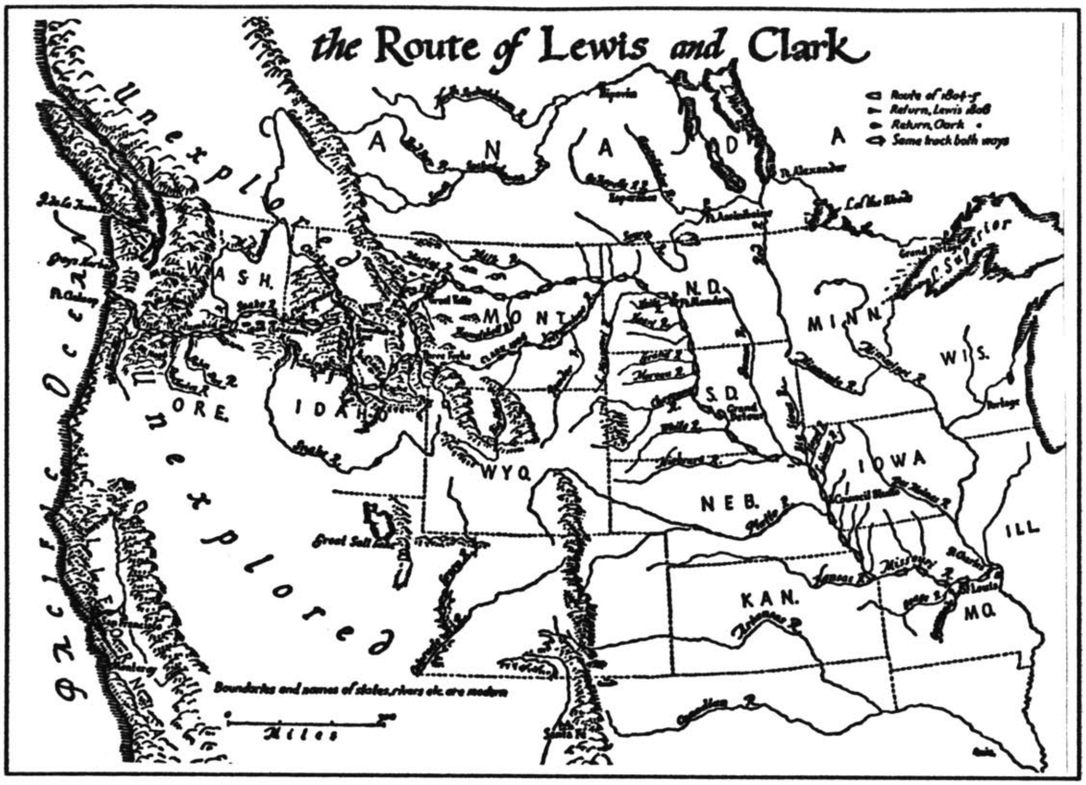
The river soon became known as the "graveyard of steamboats," and it did not take long for business interests to ask the federal government to make the river safe for navigation. In 1824 the Corps of Engineers began pulling snags

both rivers; in 1960, of course, the construction of the navigation channel in the lower Missouri was not yet complete. Finally, the Bureau of Reclamation, *Putting the Missouri to Work,* July 1, 1945, 6, said the unimproved river, at "2,475 winding miles," is "next to the longest of American streams." All of which simply proves that rivers change.

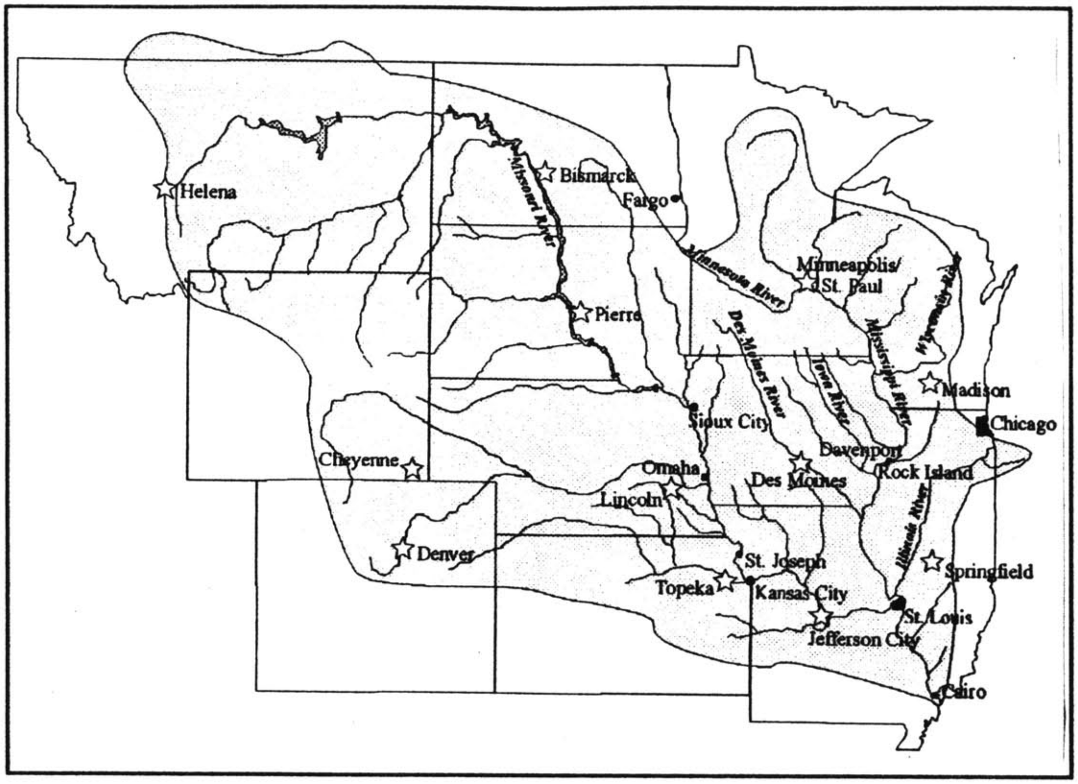
[4]From Jefferson's instructions to Lewis, quoted in Ambrose, *Undaunted Courage,* 94.

[5]MBIAC 1971, II, 18.

[6]George Fitch, quoted in Don Pierce, *Exploring Missouri River Country* (Jefferson City: Missouri Department of Natural Resources, Division of Parks and Historic Preservation, n.d.), 37.



1 The Route of Lewis and Clark (Frontispiece to *The Journals of Lewis and Clark*, ed. Bernard DeVoto)



2 Extent of Missouri and Upper Mississippi River Basins (Galloway 1994, 5)

or demolishing them with explosives, and in 1838 federal workers removed 2,245 large trees from the channel and cut 1,710 overhanging trees in a 385-mile stretch of the river upstream from St. Louis.[7] But clearing snags was not enough to make the Missouri truly navigable, and thirty years later pilots were still complaining about the dangers of a river that sank as many as 300 boats a year.[8] Most eloquent no doubt was Samuel Clemens, who recalled a six-day journey between St. Louis and St. Joseph, Missouri, in July 1861 as consisting entirely of

> a confused jumble of savage looking snags, which we deliberately walked over with one wheel or the other; and of reefs which we butted and butted, and then retired from and climbed over in some softer place; and of sand bars which we roosted on occasionally, and rested, and then got out our crutches and sparred over. In fact, the boat might almost as well have gone to St. Joe by land, for she was walking most of the time, anyhow. . . .The captain said she was a 'bully' boat, and all she wanted was more 'shear' and a bigger wheel. I thought she wanted a pair of stilts, but I had the deep sagacity not to say so.[9]

Ironically, nothing much was done to improve conditions on the river until competition from the railroad had ended the era of waterborne freight. In 1877 the last commercial vessel arrived in Fort Benton, Montana, from St. Louis, and the next year shipping interests convinced Congress to fund permanent channel improvements. "It is not the only illustration," notes historian Henry Hart, "of an industry calling in the government doctor when its disease became chronic."[10] The funding remained meager and the interventions purely local until 1884, when Congress responded to "a vociferous demand," brought on by escalating rail prices, that the government "revive the failing river commerce." It established the Missouri River Commission and charged it "to obtain and maintain a channel and

[7]MBIAC 1971, II, 24, and Henry C. Hart, *The Dark Missouri* (Madison: The University of Wisconsin Press, 1957), 78. Hart's poetic and thoroughly researched book seems to be the unacknowledged source for much information about the development of the Missouri River basin contained in later works. I highly recommend it to anyone wanting a thorough history of the struggle over water in the Missouri basin.

[8]MBIAC 1971, II, 24.

[9]Quoted in Pierce, *Exploring Missouri River Country,* 39.

[10]Hart, *The Dark Missouri,* 78.

depth of water in said river sufficient for the purposes of commerce and navigation."[11]

Under the direction of Lt. Col. C. R. Suter of the Corps of Engineers, the Commission undertook a plan that "consist[ed] essentially in contracting the width of the stream to comparative uniformity and fixing the location and direction of the channel by protecting all banks exposed to the erosion action of the current."[12] That was no small task, for the Missouri was in places more than a mile wide and less than three feet deep.[13] It meandered between low banks in numerous shallow channels around shifting sandbars and islands formed by the immense quantities of soil carried by the river, and it often moved several hundred yards overnight.[14] Suter's technical solution to the problem of a silt-laden river is still used today. He narrowed and deepened the channel by projecting wooden pile dikes into the flow, which slows the water "at the edges so that the siltation would occur there and the flow be concentrated in the middle of the reach," and he stabilized the channel by lining the outside of river bends with wood, stone, or brush.[15]

By 1901 Suter's team had in this way improved 85 miles of the river and had also removed 17,676 snags, 6,073 trees liable to become snags, and 69 drift piles.[16] But political conflicts had prevented the work from proceeding in continuous lengths, and local interests wanting "protection of their property along the banks more than facilities for through transportation on the waterway" undermined Congressional support for the project.[17] As a result, Congress abolished the Commission in 1902 and returned management of the river to the Corps of Engineers. Continued bickering, uneven funding, and low-water years led to neglect of the channel works, and within ten years as much as half of them had been destroyed.[18]

---

[11]Ibid., 79.

[12]Suter, quoted in John L. Funk and John W. Robinson, *Changes in the Channel of the Lower Missouri River and Effects on Fish and Wildlife.* Aquatic Series 11. Jefferson City: Missouri Department of Conservation, 1974, 8.

[13]SAST 1994, 97, 123, which reports that "98 percent of the channel in late summer and autumn was less than 3 ft deep during median flow conditions before regulation."

[14]Corps 1995a, MR, 10-37.

[15]Hart, *The Dark Missouri,* 80; Funk and Robinson, *Changes in the Channel,* 8.

[16]Funk and Robinson, *Changes in the Channel,* 8.

[17]Hart, *The Dark Missouri,* 80.

[18]Ibid., 81.

A new wave of settlement in the Great Plains and increased yields following completion of the first federal irrigation projects under the Reclamation Act of 1902 prompted another call for improvements to enable barges to haul crops on the Missouri River. Congress responded in 1912 with a comprehensive plan and sufficient funding to build a six-foot deep navigation channel from Kansas City to the confluence with the Mississippi. This plan, too, was hijacked by local interests unconvinced that there was sufficient commercial traffic to warrant large expenditures on navigation, and systematic channel improvements again yielded to intermittent bank protection projects.

At the same time, a series of large floods along the lower Missouri redirected attention to a problem not previously considered within federal jurisdiction. Although the Corps of Engineers had debated the value of reservoirs for maintaining sufficient flow in the channel and for providing irrigation in the plains, the government had not considered storage for flood control among its concerns. Catastrophic floods in 1844, 1882, and 1903 drew so little attention from the federal government that the Corps did not even measure flood flow, and protection in the form of levees was left to local drainage districts. But the river flooded again in 1908 and 1909, and in 1915 record rains produced five flood stages on the Kansas and Missouri rivers between May 30 and July 21. Although the state of Kansas petitioned Congress "to reopen the question of reservoirs for flood control plus irrigation," it got no response beyond a directive to the Corps in the 1916 Rivers and Harbors bill to investigate flood periods and to "devise some general plan which will best guard against the recurrence of floods and diminish their damaging effects upon the lower valleys of the Kansas, Arkansas, Missouri, and the Mississippi Rivers."[19]

Without funding, however, the general plan progressed no further than studies of siltation and hydroperiod until the enormous 1927 flood on the Mississippi, which inundated lands from Illinois to the Gulf of Mexico, made flood control a national priority.[20] In its Flood Control Act the

---

[19]Material in this paragraph comes from Hart, *The Dark Missouri*, 82–93.

[20]For a comprehensive account of the 1927 flood, see John M. Barry, *Rising Tide: The Great Mississippi Flood of 1927 and How It Changed America* (New York: Simon & Schuster, 1997).

following year, Congress directed the Corps to "submit projects for flood control on all the tributary streams of the Mississippi River. . .subject to destructive floods."[21] The Corps undertook a comprehensive study of water resources in the entire Missouri basin; and while Congress was weighing the report's recommendations, a series of fatal floods in Kansas, Nebraska, New York, and New England led it to pass the first nationwide Flood Control Act in 1936. The act not only authorized specific projects, but also, and more importantly, shifted primary responsibility for flood control to the federal government by asserting that "the prevention of floods on navigable streams or their tributaries was a national purpose under the commerce clause of the Constitution."[22] As a result, Congress in quick succession authorized nine reservoirs in tributaries close to the mouth of the Missouri, a series of agricultural levees along the stretch between Sioux City and Kansas City, and the first dams in the headwaters of the Missouri system.[23] The brand new Fort Peck Dam in northeastern Montana, photographed by Margaret Bourke-White for the cover of the inaugural issue of *Life* magazine in 1936, literally became the emblem of progress.[24]

That move into the distant reaches of the Missouri launched a new era of big plans that attempted to manage the river as one system with multiple uses. Indeed, the struggle over navigation and flood control in the lower basin was matched by the drama over irrigating the arid lands upstream.[25] The federal government, through successive homesteading and land acts, had encouraged settlement in regions unsuited for agriculture on the scale envisioned. By the end of the nineteenth century, "it was becoming apparent that the irrigation projects capable of development by private enterprise or unaided colonies of settlers were running out."[26] President Theodore Roosevelt, in his first annual message to Congress, addressed the problem:

---

[21]Corps 1995a, MR, 2-21.
[22]Hart, *The Dark Missouri*, 94.
[23]Ibid., 96, and Corps 1995a, MR, 2-21.
[24]See John E. Thorson, *River of Promise, River of Peril* (Lawrence: University Press of Kansas, 1994), 1.
[25]See Hart, *The Dark Missouri*, 98–119, and MBIAC 1971, I, 21–26; II, 31–33, 37–55.
[26]Hart, *The Dark Missouri*, 108.

> The pioneer settlers on the arid public domain chose their homes along streams from which they could themselves divert the water to reclaim their holdings. Such opportunities are practically gone. There remain, however, vast areas of public land which can be made available for homestead settlement, but only by reservoirs and main line canals impracticable for private enterprise. These irrigation works should be built by the National Government.[27]

The Reclamation Act he signed on June 17, 1902, notably required that water users reimburse the federal government for its investment. But payments to the supposedly self-replenishing Reclamation Fund never exceeded one-third of the cost invested. That fact, coupled with inadequate information about "drainage, soils, alkalinity, and amount of water to be applied, in short, the matters concerning irrigation as agriculture," resulted in the Bureau of Reclamation completing only 11 small projects over the next 42 years.[28]

In 1939 Congress found a new way to subsidize irrigation that would make the necessary large-scale projects feasible. In the Reclamation Project Act of that year, it authorized the Secretary of the Interior to allocate part of the project cost to flood control and navigation.[29] In one stroke Congress united the interests of the entire basin in dams and reservoirs and set in motion a comprehensive plan for integrated management of the water resources of one-sixth of the nation.

Initially, there were two comprehensive plans, both calling for massive infrastructure investments. The first, begun in 1939 by William Glenn Sloan of the Bureau of Reclamation but not submitted to Congress until May 1944, responded to the Dust Bowl conditions of the 1930s and focused on irrigation, reclamation, and hydroelectric power. The second, developed by Lewis A. Pick of the Corps of Engineers in response to devastating floods in the lower basin in 1943, emphasized flood control and navigation. After some lobbying from back home, Congress ordered the two agencies to reconcile the plans. It passed

---

[27]Ibid., 107.
[28]Ibid., 107–15.
[29]Ibid., 116.

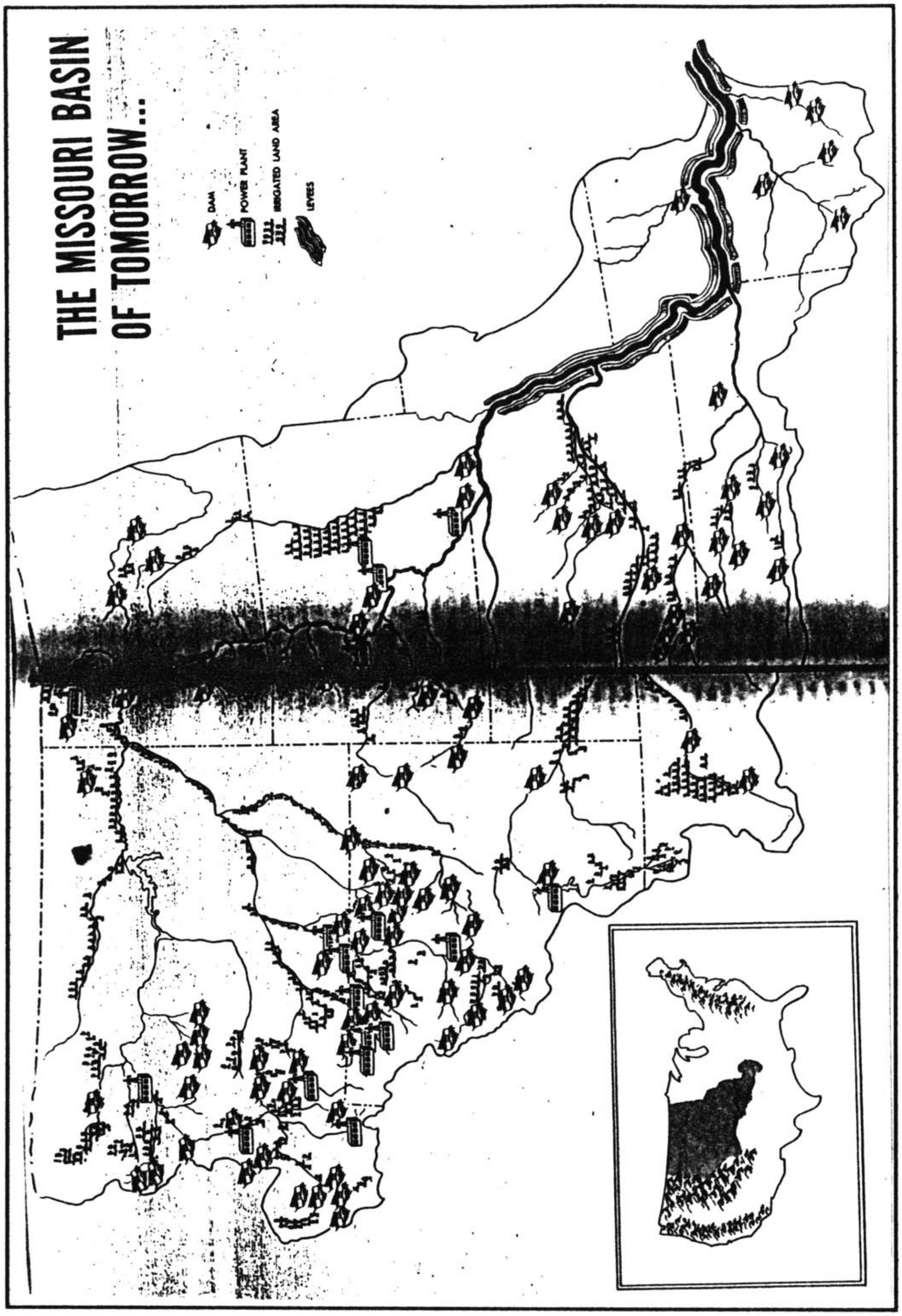
the final Pick-Sloan plan as Section 9 of the Flood Control Act of December 22, 1944.[30]

It was indeed, as the Bureau's Commissioner proclaimed in a 1945 public relations brochure, a plan of "promise and confidence."[31] One might add hubris, for it proposed nothing less than to manage every drop of water in a river system that drains approximately 513,000 square miles in this country and another 9,715 miles in Canada.[32] Residents of the huge Missouri River basin, encompassing all or part of ten states, would no longer be subjected to the "human suffering and crop failure caused by flood and drought," as the river would now take on the "job [of] serving the people it has often abused."[33] The waters of the Missouri and its tributaries, "previously wasted," were to be "put to work for the Nation" through more than 300 separate projects, including 112 dams and reservoirs with 107 million acre-feet of storage capacity, irrigation for more than 5 million "moisture-starved acres," 20 power plants to "generate the electricity needed for agriculture and industry on the scale which the Missouri Basin States should have," 19 new municipal water systems, and a 9-foot deep navigation channel plus continuous levees from Sioux City to the mouth (figure 3). And, of course, there would also be "ample water for recreation and wildlife."[34]

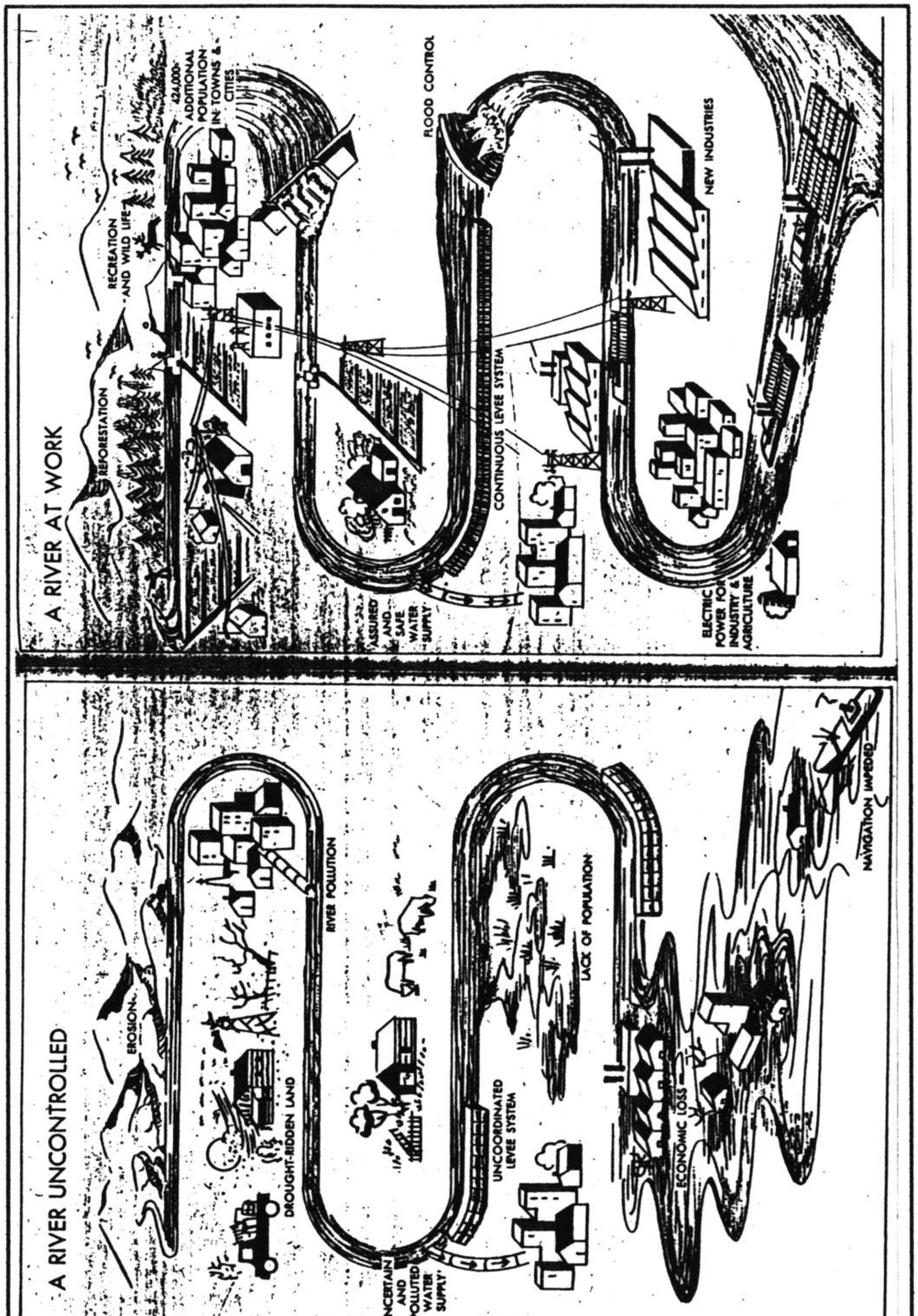
This ambitious plan to transform a "dangerous and relatively undeveloped river system into a servant of thrifty agriculture and industry"[35] (figure 4) had an element of social engineering as well. It was a massive postwar jobs program, promising 600,000 man-years of employment during construction; a homesteading act creating 53,000 new farms, many for returning veterans; and an attempt to boost the economies of the farm states by bringing an estimated 636,000 people, and the property tax revenues they

---

[30]Ibid., 120–26, and Thorson, *River of Promise, River of Peril,* 63–67. The Corps' plan is published as House Document 475 (78th Congress, 2d Session); the Bureau's as Senate Document 191 (78th Congress, 2d Session).
[31]Bureau of Reclamation, *Putting the Missouri to Work,* 2. I am indebted to the quirkily comprehensive collection of the Loeb Library at Harvard University's Graduate School of Design for this treasure of a document, which has gone unnoticed in the literature.
[32]Corps 1994, MR, 4.
[33]Bureau of Reclamation, *Putting the Missouri to Work,* 2, 4.
[34]Ibid., 4–5, and MBIAC 1971, II, 55.
[35]Bureau of Reclamation, *Putting the Missouri to Work,* 4.



3 "Missouri River Plan for Unified Development of irrigation, hydroelectric power, flood control, mineral resources, navigation, and other benefits" (Bureau of Reclamation, *Putting the Missouri to Work*, 1945)



4 "Uncontrolled, the Missouri River and its tributaries waste their basin's vast water resource. At work, the Missouri will benefit all by developing more fully the resources of one-sixth of the Nation's land area." (Bureau of Reclamation, *Putting the Missouri to Work*, 1945) generate, to underpopulated regions.[36] But perhaps most importantly, it was an assurance to the nation that the troubles were ending: the government was winning the war to end all wars, and it would complete the "conquest of a river"[37] and vanquish the twin enemies at home. Thus it promised "insurance against repetitions of the destruction of property and human values by drought" and to provide "protection. . .against all floods except those of a purely local nature."[38]

With the Pick-Sloan plan, Congress and the federal agencies believed they had finally solved the problem of water management in the Missouri basin. It would, they assured everyone, fairly distribute the benefits and pay for itself through user fees. The plan seemed ideal: water and power users would repay two-thirds of the federal investment, and the treasury would pick up the remaining third, the "nonreimbursable cost of flood control and navigation, the benefits of which accrue to the general public."[39] Properly managed, the Missouri River would "return more than twice as much as [the] yearly costs for construction, operation, and maintenance" of the vast new infrastructure.[40] The plan also promised to solve the thorny problem of allocation by storing potential floodwaters and by giving priority to upstream "beneficial consumptive use" over downstream navigation.[41] So they built the dams and reservoirs, the navigation channel, and the levees. And then it rained.

---

[36]Ibid., 12, 20.
[37]Ibid., 27.
[38]Ibid., 12, 15.
[39]Ibid., 17.
[40]Ibid., 18.
[41]From the O'Mahoney-Milliken Amendment to the Flood Control Act that authorized Pick-Sloan. The full relevant sentence is: "The use for navigation, in connection with the operation and maintenance of such works herein authorized for construction, of waters arising in States lying wholly or partly west of the 98th Meridian, shall be only such use as does not conflict with any beneficial consumptive use, present or future, in States lying wholly or partly west of the 98th Meridian, of such waters for domestic, municipal, stock water, irrigation, mining, or industrial purposes." See Thorson, *River of Promise, River of Peril*, 69, and MBIAC, II, 55.

"From an engineering standpoint, we can control. . .whatever we want to control."

Maj. Gen. F. P. Koisch, Director of Civil Works, Corps of Engineers, in Hearing before the Senate Subcommittee on Flood Control—Rivers and Harbors, July 17, 1971

2 CIVILIZED EFFECTS

It rained for six weeks in the summer of 1951, and Kansas City drowned. It rained after heavy snows in the spring of 1952, and Sioux City, St. Joseph, and 800 miles of farms and crops went under. It rained again in 1960, 1967, 1973, 1975, 1984, and 1986, and each time after the flood they built the levees higher and promised again to control the water from the minute it hit the ground.[1]

And then it rained for eight straight months in 1993. Between January and June heavy and persistent rains soaked the midwest with twice the normal precipitation for that period. In May through August, record rain fell over 26,000 square miles of the Upper Mississippi watershed,[2] and parts of the Missouri River basin received between 24 and 40 inches in the three summer months alone.[3] Along almost a thousand miles of the Mississippi and Missouri rivers, water overflowed the banks, breached levees, and ran free through city streets and across millions of acres of farmland.

The destruction was staggering. The waters broke or topped 69 percent of the levees along the upper Mississippi and lower Missouri rivers and burrowed a hole under the floodwall protecting St. Louis. Flooding extended over 15,600 square miles in nine states and damaged or destroyed 130,000 structures, including 55,000 houses, 5,000 businesses, and 33 airports. Fifty-eight municipal water systems, serving 500,000 people, were overwhelmed and shut down, and another 150 systems, serving one million people, were contaminated.[4] Along the Missouri River's main stem, no community from Nebraska City, Nebraska, to St. Charles, Missouri, was spared. St. Louis, just

[1]Corps 1994, D, 19–22; Corps 1994, E, 23–26.
[2]The Upper Mississippi basin encompasses 714,000 square miles, 74 percent of which is the Missouri River basin.
[3]Galloway 1994, 9–10.
[4]Ibid., 15–19, 48–51.

below the confluence of the nation's two largest rivers, escaped inundation only because a major levee failure upstream siphoned off considerable flow at just the right time.[5] A day and a half later, the conjoined river crested at 49.6 feet, which is 20 feet above flood stage, 36 feet above normal midsummer flow, and just 2.4 feet short of spilling over the floodwall (raised by 8 feet after the 1973 flood) and into downtown.[6]

More than half the estimated 20 billion dollars in losses were agricultural, and in some areas the damage is irreparable. Over 455,000 acres in Missouri alone, or 60 percent of the floodplain cropland in that state, were damaged by scouring and by sand deposits up to 10 feet deep.[7] Most of the damage resulted from the 500 scour holes formed by levee blowouts and breaches in the stretch between Kansas City and St. Louis. Scours up to 65 feet deep and a mile long stripped the floodplain of its alluvial deposits and exposed the underlying glacial outwash sediments. After blasting through the levees, the floodwaters slowed and dropped the sediment load in thick deposits that have ruined some land for farming (figures 5–12).

Although this flood was the direct result of unique meterological conditions, it dramatically illustrates a disturbing pattern. The magnitude of floods on the lower Missouri River, defined as the approximately 800 miles below the last dam at Yankton, South Dakota, is increasing: there have been five major floods in the last twenty years, and the one in 1995 was in some places higher and more damaging than the Great Flood two years earlier.[8] The relationship between flow and stage is changing in troubling ways as well, as a smaller flow results in higher crests (table 1). The amount of water that flowed past St. Louis, for example, was 20 percent less than in the record

---

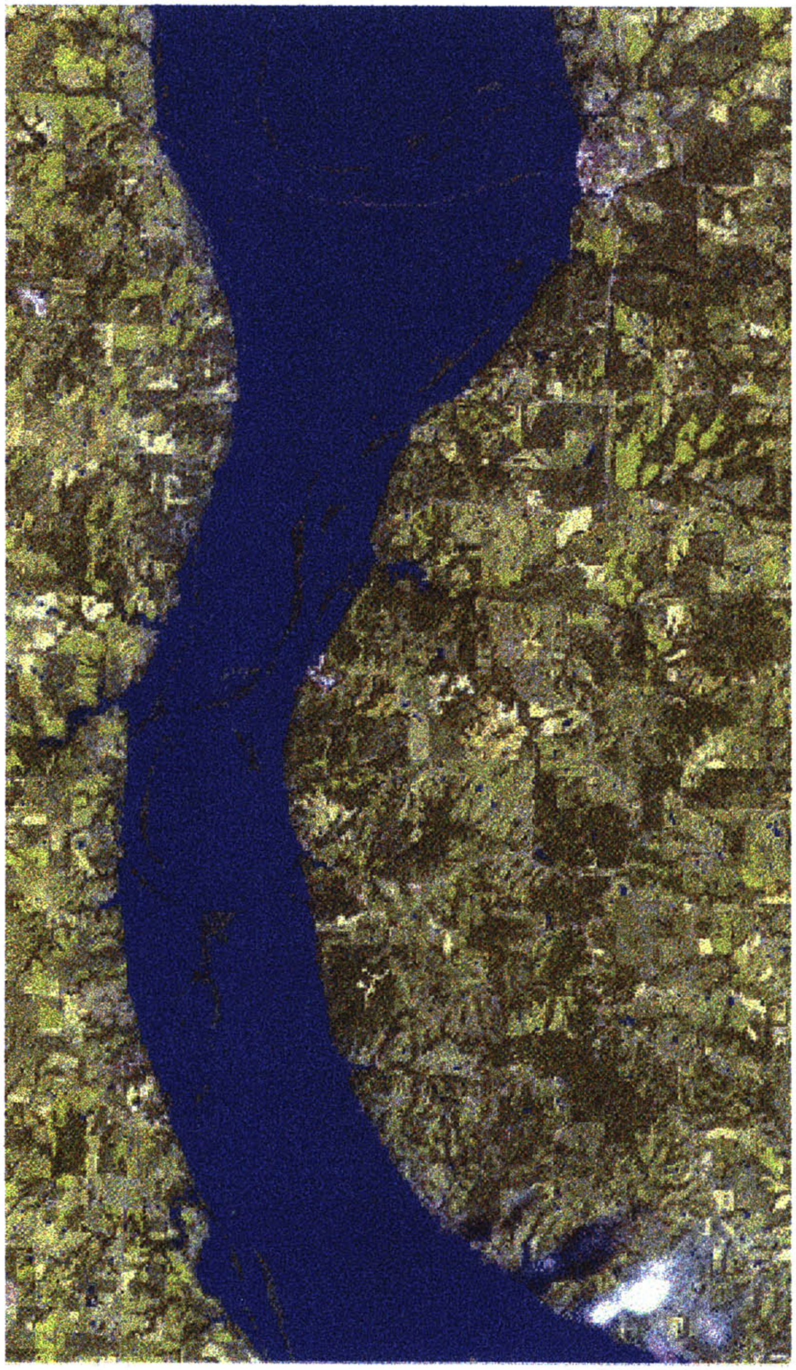
[5]Interview with Al Austin, Department of Civil Engineering, Iowa State University, April 1994.

[6]The Monarch-Chesterfield levee, protecting, among other areas, the Spirit of St. Louis Airport, failed on the evening of July 30. The highest stage recorded at St. Louis occurred on August 1. See Corps 1994, C, 15; and Corps 1994, E, 12.

[7]Data from the Soil Conservation Service, reported in Corps 1994, E, 35.

[8]Jim Auckley, "The 1995 Floods," *Missouri Conservationist: Big Rivers Special Issue* (August 1995): 5.

5 Landsat image of preflood conditions near Glasgow, Missouri, September 24, 1992. Note the bluff-to-bluff agriculture. (SAST)



6 Landsat image of peak flood conditions near Glasgow, Missouri, August 1, 1993, showing bluff-to-bluff flooding and traces of main channel (SAST)

7 Landsat image of post-flood conditions near Glasgow, Missouri, December 7, 1993. The red circles designate scour holes, and the bright white areas are sand deposits. (SAST)

8 Landsat image of post-flood conditions near Glasgow, Missouri, December 7, 1993, showing effects of levee breaches and scour holes. Very thick sand deposits appear in purple, thick in red, thin in orange, and trace amounts in yellow. (SAST)

9 Levee blowout and sand deposits near Rocheport, Missouri (Corps 1994, E, photo 4)

10 Small scour hole behind the new levee near Wilton, Missouri (Author, March 1996)

11 Sand deposits and new scour-hole lake created by a levee breach near Hartsburg, Missouri (Author, March 1996)

12 Sand deposits on farmland near Wilton, Missouri (Author, March 1996) flood of 1844, yet the crest was 8.3 feet higher.[9] The situation was similar at Kansas City, which experienced its second 500-year flood in forty years.[10] The evidence suggests that the less spectacular 5- and 25- year floods are also becoming higher, faster, and more damaging.[11]

Table 1 Flood Discharge and Stage at Hermann, Missouri
(Source: US Geological Survey[12])

Date	Discharge	Stage
June 6, 1903	676,000 cfs	29.5 ft
July 19, 1951	618,000 cfs	33.3 ft
October 5, 1986	547,000 cfs	35.8 ft

The diminished water-carrying capacity of the lower Missouri River is the result of changes in channel morphology and long-term alteration of the hydrology of the entire watershed. The large-scale river control projects and accompanying land use changes have disrupted natural hydrologic processes by interrupting runoff and recharge functions; by destroying wetlands that both store and desynchronize flood waters; and by replacing forests and prairie vegetation, which intercept rainwater and remove it from the stream

[9]Corps 1994, C, 21. St. Louis, while not on the Missouri River, is a relevant indicator, because the Missouri contributes 42 percent of the long-term average annual flow of the Mississippi at St. Louis (Corps 1995 b, A, KC-2) and contributed 45 percent of the water that flowed past the city in the 1993 flood (based on the difference between gage heights at St. Louis and at Alton/Grafton just above the confluence). Furthermore, the Mississippi is a comparably engineered river. In 1844 the estimated peak flow at St. Louis was 1,300,000 cfs and the measured stage was 41.23 ft.; in 1993 the peak flow was 1,070,000 cfs and the stage was 49.58 ft. The 1903 flood crested at just about the same flow as the one 90 years later (1,040,000 cfs), but the stage, at 38 ft., was 11.58 ft. lower.

[10]Corps 1994, E, 23–25. At Kansas City, the 1993 flood had a peak flow of 541,000 cfs and stage of 48.87 ft.; in the 1951 flood the peak flow was 573,000 cfs and the stage was 46.20 ft.

[11]Corps 1995b, A, 8, reports "a general upward rise at all discharges during the past 30–40 years," but especially in discharges above 50,000 cfs; the mean annual discharge at Hermann is 80,050 cfs, according to William H. Langer, Constance K. Throckmorton, and Steve P. Schilling, "Earth Science Issues in the Missouri River Basin–Man's Adaptation to the Changing Environment," Open-File Report 94-195 (Denver: US Geological Survey, 1994), 11. See also C. B. Belt, Jr., "The 1973 Flood and Man's Constriction of the Mississippi River," *Science* 189: 4204 (August 29, 1975): 681–84.

[12]The information appears in Norm Stucky, "A Look Back at the Great Flood of 1993," *Missouri Conservationist: Big Rivers Special Issue* (August 1995): 9. The stream gage at Hermann, at river mile 98, is the closest to the confluence with the Mississippi.

system through evapotranspiration, with impervious urban surfaces and with cultivated land that is bare during the early spring snowmelt and rainy season.

While only 10 percent of the irrigation projects envisioned by the Pick-Sloan plan materialized,[13] the Corps of Engineers did build most of the infrastructure for flood control, navigation, and bank stabilization. Completed were seven mainstem dams, whose reservoirs submerged 903 miles of the river channel and its erosion zone plus 618,441 acres of floodplain.[14] More than 95 tributary streams were impounded or channelized, and there are 1,300 small reservoirs in the tributary system. In the lower Missouri basin alone, over one million acres of valley lands were inundated by 75 federal dams on 53 streams.[15] From Sioux City to the river's mouth, the Corps also created a 732-mile-long, 9-foot-deep navigation channel by cutting off meanders and side channels to straighten the river and shorten it by 75 miles, and by building wing dikes and stone revetments to narrow it to a single, uniform channel less than 1,000 feet wide.[16] Federal, agricultural, and municipal levees flank the lower Missouri for most of its reach; there are more than 1,100 miles of federal levees on the main stem and tributaries in the lower basin and an uncalculated number of private agricultural levees.[17]

Those projects have had cascading effects. In its natural state the "Big Muddy" transported approximately 250 million tons of sediment a year past Hermann, Missouri. Construction of the mainstem dams has trapped

---

[13]John E. Thorson, *River of Promise, River of Peril* (Lawrence: University Press of Kansas, 1994), 78.
[14]Larry W. Hesse and James C. Schmulbach, "The Missouri River: The Great Plains Thread of Life." Paper delivered at the Missouri River Assembly, Bismarck, ND, June 3–5, 1990. Draft manuscript, March 1990, 12.
[15]Ibid., 14.
[16]Galloway 1994, 39; Hesse and Schmulbach, "The Missouri River," 12; SAST 1994, 115. Hesse and Schmulbach, as well as other sources, say this stretch of the river is 127 miles shorter; however, Corps 1995b, A, 3, reports that the distance from the mouth to Sioux City dropped from 807.5 miles in 1890 to 760 miles in 1941 to its present 732.3 miles. Many sources also erroneously say that the built channel is 300 feet wide, apparently because Pick-Sloan authorized a channel of that width. SAST 1994, 97, 115, gives channel width as between 800 and 1,000 feet, which a quick measurement on a current USGS 1:24,000 map confirms.
[17]Galloway 1994, 42.

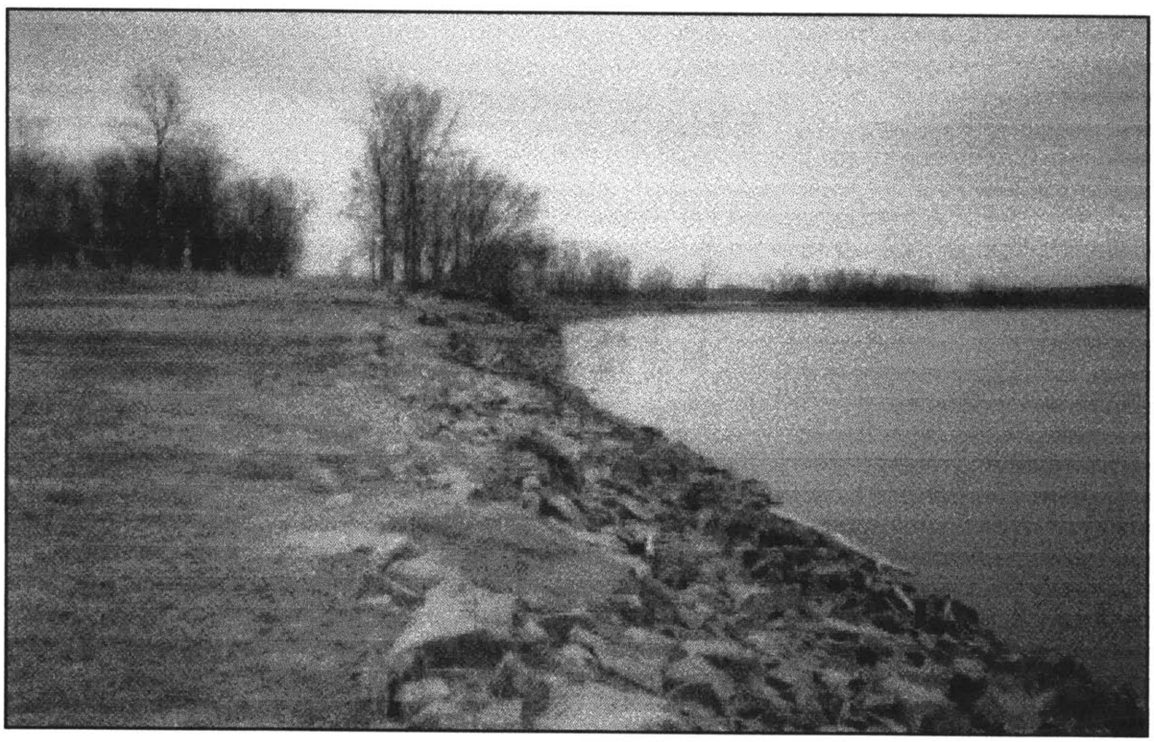
sediment in the reservoirs, and the river below the last dam "begins anew as a sediment free stream."[18] Without channelization, the river would have recovered the sediment load by eroding its banks and bed; however, the banks are now armored to prevent erosion, and, although the river does scour its bed, the wing dikes trap the suspended sediment and redeposit it to promote channel-narrowing accretion (figures 13, 14). Thus the annual sediment discharge at Hermann has dropped to between 65 and million tons.[19]

The change in sediment load has, of course, accomplished the goal of a navigable waterway by creating a faster, essentially self-dredging channel.[20] But it has created problems unintended by the engineers. Although the improved channel is supposed to alleviate flooding by quickly conveying water downstream, a combination of reduced water surface area, constricted floodplain, and bank aggradation has over time reduced the water-carrying capacity of the lower Missouri. With the wing dikes trapping sediment and filling in the slack water areas behind them, the river, as intended, lost 50 percent of its water surface area between 1879 and 1972, and the narrowed channel thus carries its flow at deeper depth.[21] In addition, overbank flows that once spread sediment over a wide floodplain are now confined by federal levees to a narrow zone 10 percent of its original width.[22] The result is that sediment deposition has raised the ground elevation riverward of the levees by as much as five feet since 1974. With the change in cross section alone, the river's water-carrying capacity has declined by 20 to 30 percent, which means that it conveys the same amount of flow at an elevation two to three feet higher.[23] It is therefore hard to avoid the conclusion that the navigation

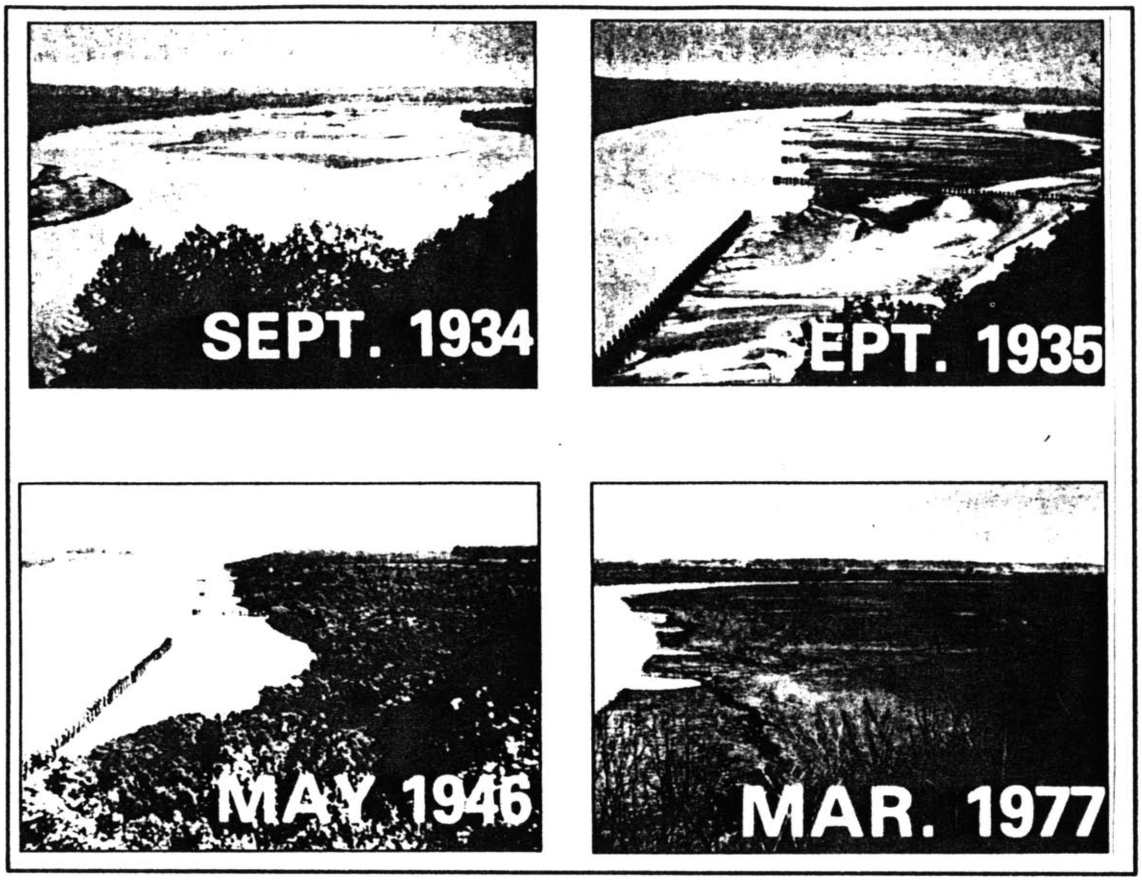
---

[18]MBIAC, VI, 51.
[19]Ibid., 53, g iving figures for the 1960s. SAST 1994, 122, generally concurs, noting that "nearly a fourfold decline in turbidity has been observed in the Missouri River at St. Louis since 1930."
[20]SAST 1994, 122; Corps 1995b, A, 7.
[21]John L. Funk and John W. Robinson, *Changes in the Channel of the Lower Missouri River and Effects on Fish and Wildlife*. Aquatic Series 11 (Jefferson City: Missouri Department of Conservation, November 1974), 3.
[22]Hesse and Schmulbach, "The Missouri River," 11.
[23]Ibid., 7. Belt, "The 1973 Flood and Man's Constriction of the Mississippi River," 681, reports that as early as 1952 Congress and the Corps attributed increased flooding on the Missouri River to the reduction in channel cross section from navigation works; he cites US House of Representatives, Committee on Appropriations, *Hearings before the Subcommittee on Deficiencies and Army Civil Functions* (82d Congress, 2d session, 1952), 41–45.

13 Wing dike with accretion of sediment, near Franklin, Missouri. Note the "discontinous, single row of trees" and the land use behind. (Author, March 1996)



14 Bank stabilization near Hartsburg, Missouri (Author, March 1996)



15 Changes in channel morphology following the addition of navigation dikes, Indian Cave Bend, north of Rulo, Nebraska. Note the lush riparian vegetation that sprouted on the new land and was then cleared for cultivation. (Galloway 1994, 54, from US Army Corps of Engineers)

works reduce the "capacity and level of protection provided by levees."[24]

Exacerbating the impact on flood stage is the private agricultural levee system. When siltation fills the area behind the dikes or between an island and the bank, the new land becomes the property of adjacent landowners. The accreted land plus the 500 to 1,500 foot strip before the federal levee, if there is one, form a parcel large enough to make cultivation worthwhile (figure 15); indeed, the reach between Sioux City and the mouth has lost 83 percent of its channel and erosion zone through this process.[25] To prevent crop damages from overbank flow in the new fields, farmers construct their own levees at or near the river's edge.[26] Those private levees, based on observations during the 1984 and 1993 floods as well as on subsequent modeling, have increased flood stages by as much as 4.8 feet.[27] In addition, during the 1993 flood some private levees "concentrated flows against the federal levees and caused erosion damage."[28]

The security promised by both the federal and private levees has increased settlement in and cultivation of the floodplain on both sides of the structures, with devasting consequences for native vegetation and wetlands. The natural riparian forest system, which had covered 76 percent of the floodplain in 1826, declined to only 13 percent in 1972 and now covers less than 1 percent. At the same time, cultivated land increased from 18 to 83 percent (table 2), and row crop agriculture has replaced 95 percent of the native vegetation along the lower Missouri River.[29] Those changes in land cover have altered the region's water budget in ways that may increase flooding. Forests both intercept and transpire more water than crops,[30] so a

[24]Corps 1995b, A, 5.
[25]SAST 1994, 122.
[26]Ibid., 164; Corps 1995b, A, 5.
[27]Corps 1995b, A, 5, 36.
[28]Ibid., 5.
[29]Galloway 1994, 55; SAST 1994, 123. See also Thomas B. Bragg and Annehara K. Tatschl, "Changes in Flood-plain Vegetation and Land Use Along the Missouri River from 1826 to 1972," *Environmental Management* 1: 4 (1977), especially 346, Table 1, which gives changes in land use by river segment at four dates, and 347, Table 2, which presents the frequency by maturity of dominant tree species in 1826 and 1972.
[30]The numbers vary greatly depending upon the type of crop and the season. For a range of values, see Thomas Dunne and Luna B. Leopold, *Water in Environmental Planning* (New York: W. H. Freeman and Company, 1978), 88–90; 147, citing A. Baumgartner, "Energetic Bases for

significant reduction in forest cover increases the amount of water available for either infiltration or runoff. "The stripping of forests and their replacement by crops," however, "often lower[s] the infiltration capacity [of the soil] drastically" and thus increases the amount of surface runoff and the potential for flooding and soil erosion. Furthermore, crops may not cover the ground as efficiently as native vegetation nor maintain as high an organic content in the soil, both of which also affect infiltration.[31] Finally, 170 years of farming in the lower Missouri basin have stripped off the porous, permeable topsoil, the loss of which is contributing to the increase in the frequency and magnitude of floods by causing runoff that is now five to six times greater for a moderate rainfall of 2.5 inches.[32]

Table 2 Land Use/Land Cover in the Lower Missouri River Floodplain
(Data compiled from Corps 1995a, C1)

Cover Type	**Acres**	**Percent**
Agriculture	1,902,410	83
Urban	114,620	5
Range	24,790	1
Upland Forest	6,280	<1
Forested Wetland	57,300	3
Nonforested Wetland	72,900	3
Water	107,010	5
Barren	1,730	<1
Total	**2,287,040**	**100**

Differential Vapourization from Forest and Agricultural Lands," in *Forest Hydrology*, ed. W. E. Sopper and H. W. Lull (Oxford: Pergamon Press, 1967), 381–89; and S. Tajchman, "Evapotranspiration and Energy Balances of Forest and Field," *Water Resources Research* 7 (1971): 511–23.

[31] Dunne and Leopold, *Water in Environmental Planning*, 168.

[32] Scientist Jim Knox, in an interview in the "Nova" documentary *Flood!*, 1994; Donald L. Hey and Nancy S. Philippi, "Flood Reduction through Wetland Restoration: The Upper Mississippi Rive Basin as a Case History, *Restoration Ecology* 3: 1 (March 1995): 14, note that "in its original state, the soil held 0.31 inches of water per inch of soil; in an eroded state, it holds 0.04 inches per inch. The basinwide [meaning entire Upper Mississippi basin] capacity to hold water in the top 18 inches of soil has thus been reduced by almost 18 million acre-feet, 45% of the flood volume of 1993." They note as well that "over the past 150 years, we have lost as much as 70% of the water-holding capacity of our soils" (p. 12, citing N. C. Brady, *The Nature and Property of Soils* [New York: MacMillan Publishing Company, 1990]).

Land conversion for agriculture has also destroyed most of the wetlands in states along the lower Missouri River. Iowa and Missouri, for example, have lost 89 and 87 percent, respectively, of the wetlands that existed in 1780.[33] Most were upland wetlands intentionally drained to gain more tillable acreage; the rest are riparian wetlands lost in the modification of the river channel. Wetlands play an important role in regulating water level in a catchment. They provide natural storage both as depressions in the landscape and because they hold more water than equivalent areas of soil.[34] Their vegetation "acts as a sponge to hold water for slow release,. . . retards runoff and increases the rate at which water infiltrates the soil."[35] In upland areas, the combination of land conversion from natural vegetation to row crops plus open ditch drainage "increases peak runoff at the field edge by a factor of 200 to 400 percent over the natural condition."[36] When more sophisticated subsurface tile drainage systems replace the open ditches, those peak flows are lowered by 35 to 55 percent; but the net result is still that "agricultural drainage increases flow in streams over surface flow from natural systems"[37] and thus increases as well the risk of flooding. With more water reaching the streams, the loss of riparian wetlands then becomes critical, as they are especially effective at desynchronizing the release of water from tributaries, so that "not all flood waters reach the main channel at the same time."[38]

Even the dam and levee builders have long recognized the value of wetlands for reducing flooding. After a 1972 study showing that the

---

[33]Galloway 1994, 44; and Langer, et al., "Earth Science Issues in the Missouri River Basin," 25, 26 (map).
[34]Katherince C. Ewel, "Multiple Demands on Wetlands," *BioScience* 40: 9 (October 1990): 663. SAST 1994, 86, reports that the existing wetlands in North Dakota, which has lost 50 percent of its wetlands since 1780, "store about 72 percent of the total runoff from a 2-year frequency flood and 41 percent of the total runoff from a 100-year frequency event." Admittedly, North Dakota has a different soil and moisture profile from the lower Missouri states, and the storage is less in areas with shallower depressions, but it's a valuable reminder of the importance of wetlands.
[35]Michael W. Binford and Michael J. Buchenau, "Riparian Greenways and Water Resources, in Daniel S. Smith and Paul Cawood Hellmund, eds., *Ecology of Greenways* (Minneapolis: University of Minnesota Press, 1993), 75.
[36]Corps 1995b, A, SP-18.
[37]Ibid.
[38]Michael Williams, "Understanding Wetlands," in Michael Williams, ed., *Wetlands: A Threatened Landscape* (Oxford: Basil Blackwell, 1990), 15.

combination of development and levees would increase flood damages by 17 million dollars a year, the Corps of Engineers decided to purchase or arrange easements on 8,800 acres of floodplain wetlands in the upper Charles River basin in Massachusetts rather than spend 100 million dollars on structures to protect downstream Boston.[39] The rationale was simple: "Nature has already provided the least-cost solution to future flooding in the form of extensive wetlands which moderate extreme highs and lows in stream flow. Rather than attempt to improve on this natural mechanism, it is both prudent and economical to leave the hydrologic regime established over the millenia undisturbed."[40]

Disturbing the hydrologic regime in the lower Missouri basin has had consequences beyond an increase in destructive floods. The river control structures and land use changes have transformed the basin's ecosystems, and numerous species are struggling to survive. Nearly thirty years ago scientists bemoaned that "channelization has wiped out over 60 percent of our wildlife habitat."[41] The situation has since become critical. With the reduction in sediment and the swifter current has come the loss of 98 percent of the surface area of river islands and 97 percent of sandbars.[42] Forty-six species of fish, two-thirds of the total in the lower Missouri ecosytem, rely on sandbars and islands, and those habitats are also important nesting and feeding areas for such federally listed endangered species as the interior least tern and piping plover.[43] Cattail marshes, though never occupying more than 10 percent of the surface area between normal high-water marks, were home to more than

---

[39]William J. Mitsch and James C. Gosselink, *Wetlands,* 2nd ed. (New York: Van Nostrand Reinhold, 1993), 519; interview with Dick Heidebrecht, US Army Corps of Engineers, Planning Directorate, Basin Management Division, Waltham, MA, March 1994.

[40]Corps 1972 report, quoted in *A Casebook in Managing Rivers for Multiple Uses* (Washington, DC: National Park Service, Association of State Wetland Managers, and Association of State Floodplain Managers, 1991), 7.

[41]Bill Dieffenbach, water resource specialist with the Missouri Department of Conservation (now retired), quoted in Stewart Udall and Jeff Stansbury, "Watch on the Upper Mississippi: A 12-Foot Channel?" *St. Paul Sunday Pioneer Press,* Janaury 31, 1971, reprinted in *The Effect of Channelization on the Environment. Hearing Before the Subcommittee on Flood Control—Rivers and Harbors of the Committee on Public Works, United States Senate, Ninety-Second Congress, First Session, July 27, 1971* (Washington, DC: US GPO, serial no. 92-H24, 1971), 310.

[42]Galloway 1994, 53.

[43]SAST 1994, 122.

90 percent of the river's fish community.[44] Now that most of such marshes are gone, along with the overhanging trees providing shade and nutrients to the channel, the lower Missouri basin has 26 species of fish listed as rare, threatened, or endangered.[45] Lake sturgeon have disappeared entirely, while blue catfish and pallid sturgeon are rare throughout their traditional range.[46]

Aquatic organisms are not the only losers, of course. With overbank flow generally confined to a narrow strip, the larger floodplain is deprived of the seasonal fluctuations in water level and the nutrients necessary to sustain native plants and animals. Riparian and upland systems, like aquatic ones, suffer from a change in the composition and diversity of habitats, with a corresponding reduction of species richness and diversity. Gone are the mature floodplain forests, with their stands of black walnut, pawpaw, sycamore, hackberry, and elm; in their place are straggly rows of willow and cottonwood, known to be pioneer species in the region.[47] Gone, except for isolated patches and recently restored preserves, is the tallgrass prairie, with its big bluestem, prairie cordgrasss, and Indian grass. And on their way to extinction are species ranging from the American burying beetle to the peregrine falcon (tables 3, 4).

The decimation of natural features by the manmade alteration of stream systems across the country was so evident by 1971 that the Senate held hearings to address the problem. It opened with an eloquent statement from Senator James L. Buckley of New York:

> The purposes sought to be achieved by stream channelization have been of the highest order, namely, the reduction and elimination of damage caused by flooding and erosion in our nation's watersheds. Yet

---

[44]Hesse and Schmulbach, "The Missouri River," 14.
[45]Galloway 1994, 55. See also Andrew Brookes, *Channelized Rivers: Perspectives for Environmental Management* (New York: John Wiley & Sons, 1988), 136–40.
[46]Ibid.
[47]Bragg and Tatschi, "Changes in Flood-plain Vegetation," 347; W. Carter Johnson, Peggy W. Reily, L. Scott Andrews, James F. McLellan, and John A. Brophy, *Altered Hydrology of the Missouri River and Its Effects on Floodplain Forest Ecosytems.* Bulletin 139 (Blacksburg: Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, 1982), 1–3.

Table 3 Rare, Threatened, and Endangered Species in the Lower Missouri River Floodplain
(Data compiled from Corps 1995a, C1)

Group	**State**	**Federal**
Plants	15	7
Insects	1	6
Mussels	0	2
Fish	16	10
Amphibians	0	0
Reptiles	5	4
Birds	15	14
Mammals	2	3
Total	**54**	**45**

Table 4 Rare, Threatened, and Endangered Species Listed by the State of Missouri
(Source: Missouri Department of Conservation[48])

Group	**Rare**	**Threatened**	**Endangered**
Lichens	3	2	14
Bryophytes	21	0	55
Ferns & Allies	4	2	11
Flowering Plants	63	41	168
Flatworms	0	0	1
Mollusks	10	4	13
Arachnids	0	0	0
Crustaceans	9	9	3
Insects	31	6	3
Fish	21	17	18
Amphibians	6	8	0
Reptiles	6	2	6
Birds	12	9	10
Mammals	7	2	4
Total	**193**	**169**	**306**

[48]Missouri Department of Conservation, "Endangered Species in Missouri," pamphlet, November 1995.

> because our knowledge of ecological relationships has been inadequate; because we have largely failed to appreciate the biological, and therefore the economic, importance of such areas as swamps and marshes; and because of the impatience inherent in the race, at least in *Homo-Americanus*, we have too often spent very large sums in efforts which have had the net effect of compounding the injuries which we have sought to avert, and in producing biological wastelands in the process.[49]

The hearings were in part a response to the passage of the National Environmental Policy Act of 1969, which required "that a satisfactory statement of environmental impact be issued as a precedent to any [federal] project's approval."[50] While that law could change the way the government conducted business in places like the lower Missouri basin, it could not change the expectations it had instilled in the *Homo-Americanus* who lives there. For some residents, there can never be enough structural flood control, no matter what the economic or environmental cost. A year after the Great Flood of 1993, it was "pretty well forgotten, and everything's back to old ways."[51] People who had lost their homes eight times in fifteen years were rebuilding in the floodplain and asking the government to construct new downstream reservoirs and "higher levees to prevent this from happening again."[52] As long as the government promises to subsidize private property by building protective infrastructure with funds from the national treasury—for under Pick-Sloan landowners were never asked to repay the costs of flood control[53]—and as long as it assumes the risk of development in flood hazard areas by indemnifying owners against loss of property and crops, some will continue to build and to farm and to believe that "without proper flood control, all will be lost."[54]

---

[49]*The Effect of Channelization on the Environment. Hearing Before the Subcommittee on Flood Control—Rivers and Harbors,* 2.
[50]Ibid.
[51]Interview with Al Austin. I heard the same words from virtually everyone with whom I spoke.
[52]Anecdotal information, plus Galloway 1994, 125; comment from a farmer included in a summary of public meetings in Corps 1995b, D, 11, following the section divider "June Comment Spreadsheets."
[53]Henry C. Hart, *The Dark Missouri* (Madison: University of Wisconsin Press, 1957), 142.
[54]Comment included in summary of public meetings in Corps 1995b, D.

But others learned that all the engineering cannot change one simple fact: nature presents uncertainty. Though our impulse "is to tighten control on the river itself to offset the vagaries of water at the earlier stages of the hydrologic cycle,"[55] we can see that in the long run it is futile. Our investment nationwide in flood control structures exceeds $25 billion, yet "flood damages have been steadily increasing and now average more than $2 billion a year."[56] Many of those who heard the roar of collapsing levees and watched their lives wash away were surprised to find that the flood brought benefits as well. It demonstrated how quickly fish and wildlife respond to the reconnection of the river and its floodplain, as new sandbar, chute, and wetland habitat attracted both large numbers and many species of birds.[57] It destroyed many introduced and invasive plant species not adapted to flooding, enabled previously threatened native sedges to reestablish themselves, and carried the seeds of bottomland hardwood trees to new areas in the floodplain.[58] It produced record crop yields in some areas the following year, which helped farmers rediscover the benefits of periodic flooding for renewing overworked and overprocessed cropland. In the end, perhaps the greatest effect of the flood was also the most civilizing. We learned that "it is only [our] expectations that nature thwarts."[59]

---

[55]Hart, *The Dark Missouri*, 22.
[56]Philip B. Williams, "Flood Control vs. Flood Management," *Civil Engineering* (May 1994): 51, citing the 1992 report of the Federal Interagency Floodplain Management Task Force.
[57]SAST 1994, 130.
[58]William H. Allen, "The Great Flood of 1993," *BioScience* 43: 11 (December 1993): 736–37.
[59]Hart, *The Dark Missouri*, 208.

"From the Bluff. . .the most butifull prospect of the River up & Down and the Countrey Opsd. prosented it Self which I ever beheld; The River meandering the open and butifull Plains, interspursed with Groves of timber, and each point Covered with Tall timber."
Meriwether Lewis, Journal, July 30th Monday 1804

3 Natural Changes

The engineered system was predicated on the notion that it could guarantee certainty in what had been, for some human purposes, an unpredictable system. Its designers promised to substitute fixed property lines for the eroding edges and shifting boundaries caused by a river on the move. They promised reliable, and cheap, transportation. And they promised that "floods, which year after year have inundated farms and cities, will be stopped."[1] In the aftermath of the Great Flood of 1993, and of devastating floods again in 1995, it is time to acknowledge that the promises can never be kept. With well-intentioned zeal and not a little hubris, the engineers substituted a set of manmade controls, the consequences of which they did not fully understand, for natural controls that, viewed from a different spatial and temporal scale, created a balanced system with rather predictable, cyclic processes.

They also helped steal from the public the "butifull prospect" from the bluffs of the lower Missouri River. The monotony of a smoothed, uniform river and denuded landscape strips the view of its former grandeur. Drop into the valley, and it is nearly impossible to see the river at all. Private property, levees, and flood walls deny the public access to the river, and many people see it only when they cross over on a highway bridge. Lucky hikers and bikers can catch glimpses as they traverse the Katy Trail, a restored railroad corridor that passes through small towns across two-thirds of Missouri and occasionally dips within view of the water. Gamblers may see it from the decks of moored casino boats, though it would be a good wager that few come for the scenery. And the state of Missouri has recognized a public stake in the river by providing 23 boat access and fishing points between St. Louis and the Iowa border. But the engineered system, designed to protect adjacent property

[1] US Department of the Interior, Bureau of Reclamation, *Putting the Missouri to Work* (Washington, DC: July 1, 1945), 5.

and to ensure commerce, largely excludes the people who pay for its upkeep and fosters in them a perception of the river as a problem, rather than a resource. It is, after all, hard to value a river you cannot see until it laps at your door.

In this chapter, I argue that is time to accept the inherent dynamism of the Missouri River, to grapple with the primacy of navigation and the tyranny of private property, and to reestablish a more natural regime in the lower basin, below the last dam at Yankton, South Dakota. I begin with several premises:

- The engineered system, as argued in chapter 2, has created hydrologic, ecologic, and economic problems.
- The engineered system depends on an inequitable allocation of benefits and costs that is increasingly difficult to justify. It provides concentrated benefits—by giving new land to adjacent landowners, protecting their boundaries and investment, and subsidizing the barge industry—but imposes diffuse costs, as it is paid for by all taxpayers through direct expenditures on maintenance and indirect expenditures through federal crop insurance, flood insurance, and emergency bailouts.
- The engineered system privileges the wrong balance of human uses. At great expense, it ostensibly protects floodplain agriculture, while fostering land uses and flood control measures that exacerbate flooding and endanger populous urban areas downstream. It also diverts water from a booming tourism industry in the upper basin to maintain an under-used navigation channel. Furthermore, the lower Missouri river has untapped amenity and recreational value.
- The navigation channel, a prime contributor to the linked set of problems, has outlived its purpose and can no longer be justified.

I propose redressing the false promises and real damages of the engineered system by restoring the channel and riparian zone of the lower Missouri River. I argue for envisioning the optimal restoration, not one defined at the outset by short-term political considerations. To that end, I propose gradually dismantling the navigation channel, reconfiguring the levees, and pushing fixed infrastructure and agriculture back from the river's edge. The restoration has three primary functional objectives:

- Reestablishing a natural hydrologic regime, with seasonal fluctuations in water level and a "normal" flood pulse and disturbance regime.
- Reconnecting the river and its floodplain to promote creation of new backwater, wetland, and riparian areas for storage and habitat.
- Recovering aquatic and terrestrial ecosystems over time.

In the sections that follow, I summarize restoration activities underway in the lower basin and present my rationale for a different approach. I then offer a set of recommendations that addresses where to concentrate restoration efforts, how to stage the reconfiguration of the manmade system, and over what time frame. The discussion considers how to plan land uses in a dynamic system and speculates about the shape and behavior of a restored river and about how to accommodate the different pattern of uncertainty the restoration unleashes.

Restoration Plans

The lower Missouri River basin as it exists today was configured by both big plans and local interventions in a series of crises and responses that misunderstood the consequences for the whole system. The Great Flood touched off another round of crisis-driven actions and local interventions, shaped by human tragedy, economics, and politics. In that atmosphere, however, the public debate did reach consensus "that some change from the traditional approach to managing big river floodplains is in order."[2] For many state and federal agencies, the first step is buying floodplain land and moving threatened populations. The Federal Emergency Management Agency, for example, considered buying an entire levee district in Iowa once the Corps of Engineers decided that spending another $0.75 million to repair a levee it has rebuilt 14 times in 30 years made no economic sense.[3] Before

[2]Missouri Department of Conservation, "Vision Statement and Commission Recommendation" (October 27, 1995).

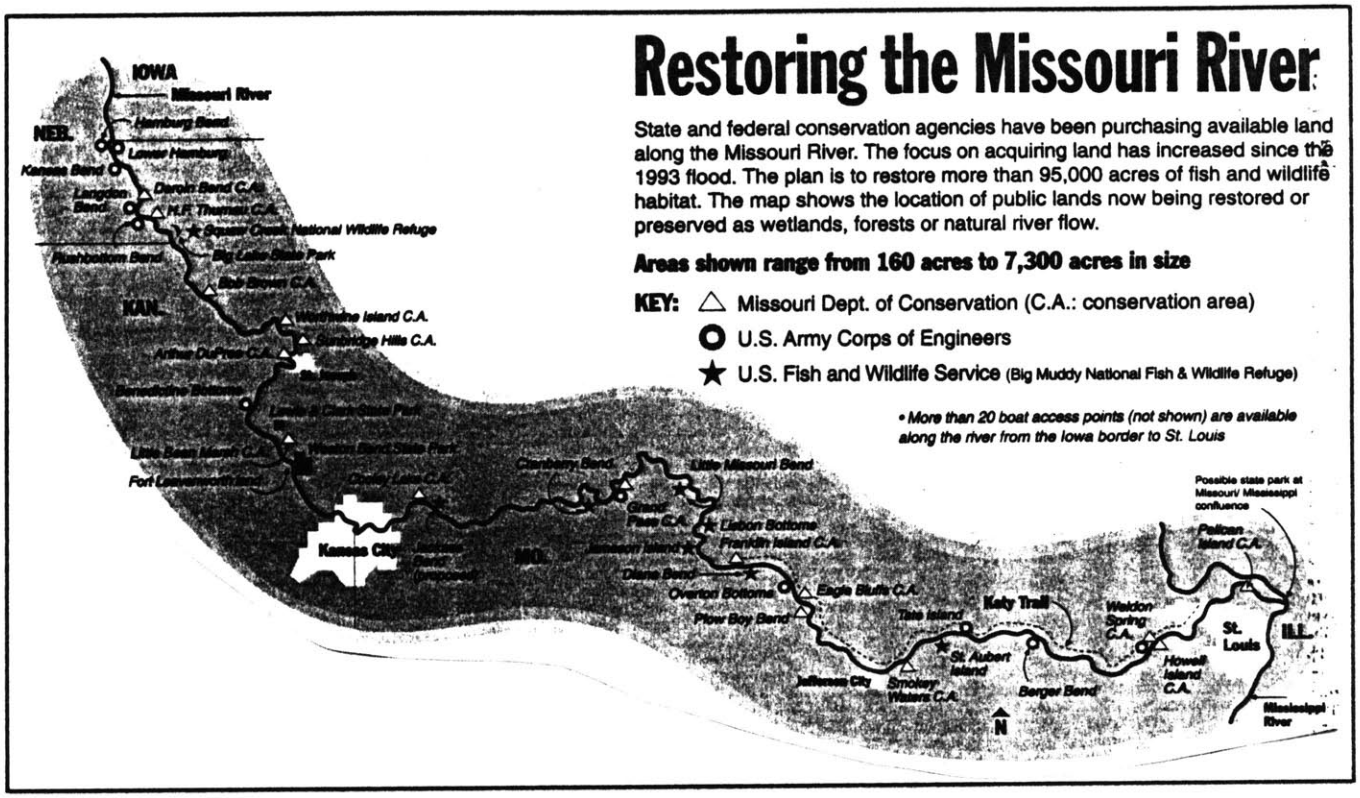
[3]Information on Louisa 8 comes from an interview with Wayne Fischer, US Fish and Wildlife Service, Illinois, April 1994.

FEMA could act, however, landowners who no longer wished to farm approached the Mark Twain Wildlife Refuge to see if it wanted to purchase their property. In the end, all owners in Louisa County's nine-square-mile levee district 8 agreed to sell their land to the Iowa Natural Heritage Foundation for conversion back to natural floodplain use.

In addition to moving people away from high-hazard areas, state and federal agencies, national environmental organizations, and local conservation groups advocate purchasing lands to combine floodwater reduction with habitat restoration. The Partnership for Missouri Wetlands is targeting for acquisition and restoration 32,000 acres in 25 counties.[4] The Missouri Department of Conservation eventually would like to purchase 20,000 acres of "flood-impacted lands"[5] and is focusing on the stretch between Kansas City and St. Louis, which has flooded six times since 1951.[6] Its efforts are part of a "fifty year vision" it shares with the US Fish and Wildlife Service (FWS) and the Corps of Engineers to reclaim for public benefit 10 percent of the Missouri River floodplain (figure 16).[7] FWS, for example, hopes to acquire 60,000 acres over 30 years for the Big Muddy National Fish and Wildlife Refuge, for which it currently has committed $2 million for 5,000 acres at seven sites. The Corps will spend $75.7 to acquire and develop 30,000 acres in a four-state area and will buy 14,000 acres along the mainstem to lease to the Kansas Department of Wildlife and Parks as its only Missouri River wildlife area. These agencies believe that "surely we can do more with something as precious as the Missouri River than make a ditch out of it," but all concede that "the whole thing is driven by willing sellers."[8] As the crisis receded, however, "the line of willing sellers dried up," and the majority of allocated funds remain in the coffers.[9]

---

[4]Corps 1994, B, 3F-18.
[5]Missouri Department of Conservation, "Vision Statement and Commission Recommendation."
[6]David Tanenbaum, "Rethinking the River," *Nature Conservancy* (July-August 1994): 14.
[7]Missouri Department of Conservation, "Vision Statement and Commission Recommendation"; Bill Graham, "Restoring nature to the Missouri," *The Kansas City Star*, Thursday, March 28, 1996, A-4.
[8]J.C. Bryant, manager of the Big Muddy National Fish and Wildlife Refuge, and Norm Stucky, planning department, Missouri Department of Conservation, respectively; quoted in Graham, "Restoring nature to the Missouri," A-4.
[9]Jim Auckley, "The 1995 Floods," *Missouri Conservationist: Big Rivers Special Issue* (August 1995): 6.



16 Conservation efforts along the river in Missouri (Dave Eames, *The Kansas City Star*, Thursday, March 28, 1996, A-4)

The constraint, and ultimately the lack, of voluntary sales is only one hitch in a plan "to restore enough [of the river] to make a difference."[10] While biologists already see "a big increase in the number of bird species" using areas reclaimed since the floods, these remain "island[s] of wilderness bordering the vast. . . private fields" that are bare most of the year and generally inhospitable to wildlife.[11] It is not clear that these disconnected patches alone will provide either enough habitat or sufficient refugia for a recovery of threatened and endangered terrestrial species. And they fail entirely to address the plight of aquatic species or a restoration of the hydrology upon which both ecosystem recovery and flood management depend.

For political reasons, the agencies not only refuse to identify critical areas for restoration, but also fail to address directly the engineered system.[12] The doctrine of willing sellers precludes battles with vested interests over whose rights take precedence, so the planners ignore the most important disrupter of the symbiotic link between the river and its floodplain.[13] For any rehabilitation to succeed in redressing the underlying problems of the Missouri River, it must begin with the "renewal of physical and biological interactions between the main channel, backwaters, and floodplains."[14] That means dismantling the navigation channel, pushing back the levees, and setting the river free to recreate a natural riparian zone.

The primary rationale for the engineered system in the lower basin—navigation—is no longer viable, is not the best economic use of the resource, and vies with upstream, more beneficial uses as defined by the Milliken Amendment. The Pick-Sloan plan calculated that increased commercial

---

[10]Norm Stucky, quoted in Graham, "Restoring nature to the Missouri," A-4.
[11]Graham, "Restoring nature to the Missouri,"A-4.
[12]Ibid; interview with Dan Dickneite, Chief of Planning Division, Missouri Department of Conservation, Jefferson City, March 1996; interview with Roger Pryor, Director, Missouri Coalition for the Environment, St. Louis, March 1996.
[13]There is an extensive literature on the negative ecological effects of channelization; for one summary, see Michael W. Binford and Michael J. Buchenau, "Riparian Greenways and Water Resources," in Daniel S. Smith and Paul Cawood Hellmund, eds.,*Ecology of Greenways* (Minneapolis: University of Minnesota Press, 1993), 85.
[14]James A. Gore and F. Douglas Shields, Jr., "Can Large Rivers Be Restored?" *BioScience* 45: 3 (March 1995): 151.

navigation justified the investment in an improved channel; in its economic assumptions, it predicted that an improved channel would lead to annual commercial haul of 5 million tons.[15] But commercial cargo peaked at about 3 million tons in 1977, has declined steadily since, and by 1990 had dropped to 1.3 million tons a year.[16] By contrast, in most years barges on the river carry two or three times that much material for reinforcing the engineered waterway itself.[17] Furthermore, the shipping season, roughly the ice-free months of April through November, will soon be shortened by at least a month, as the Corps of Engineers intends to replace the year-round uniform flow in the river with a fluctuating one—by increasing the flow in the spring and lowering it in the fall—to aid the recovery of fish.[18]

The economic benefit of the navigation channel has been suspect from the outset, and there is no evidence that it saves in transportation costs as much as the nation invests to maintain it. Although farmers argue that closing the Missouri to navigation and switching to rail transport would increase their shipping costs by $12 million a year, we spend far more than the $4.5 million a year in maintenance predicted under Pick-Sloan in 1945.[19] Furthermore, upstream interests counter that maintaining the navigation depth in low-water years protects a $20 million a year shipping business but endangers the $64 million a year sport fishing and tourism industry in the Northern Plains states.[20] In short, we maintain at great public cost a system that is not economically feasible, that benefits a few interests, and that undermines expensive flood control efforts.

Recommendations

As part of a long-term rehabilitation of the river system, floodplain acquisitions, restoration of upland wetlands and tributary systems, and even

---

[15]John E. Thorson, *River of Promise, River of Peril* (Lawrence: University Press of Kansas, 1994), 78.
[16]Ibid.
[17]Ibid., and interview with Roger Pryor.
[18]Interview with Roger Pryor; interview with Dan Dickneite.
[19]Bureau of Reclamation, *Putting the Missouri to Work*, 19.
[20]*Boundaries Carved in Water* (Missoula, MT: Missouri River Management Project, Northern Lights Research and Education Institute, 1988), 21; Mark Lawrence Ragan, "Uncle Sam Tries to Part the Waters," *Insight* (June 25, 1990), 27.

reconfiguration of water and land uses in the entire basin are essential. But it is important to begin with the one component that will achieve the most significant hydrological and ecological improvement: the channel and its immediate floodplain. I propose gradually taking apart the engineered system on the mainstem river below the last dam and especially in the stretch between Kansas City and the mouth of the Missouri River, which routinely suffers the most flood damage and has 57 percent of the repeatedly rebuilt structures in the basin.[21] Furthermore, I envision a time scale sufficient to allow natural processes to reassert themselves and do the work of river and ecosystem restoration. Unlike other river restoration plans, mine does not propose recreating through engineering something resembling a naturally sinuous river, for considerable evidence suggests that high-energy channels that "have been straightened may regain their original size and sinuosity in the absence of maintenance."[22] And unlike other restoration plans in the basin, it is not framed by the cooperation of willing sellers. I focus instead on measures that address functional objectives, namely:

- gaining the greatest hydrologic benefit by reconnecting the river and its floodplain and thus restoring a natural flood pulse
- coordinating with ecological and wetland restoration projects already underway
- maintaining "flood control" benefits during the transition; that is, making changes in a way that least disrupts the expected benefits of structural flood control
- handling flood waters from tributaries at their confluence with the Missouri River
- focusing on areas repeatedly washed out and requiring frequent rebuilding
- making the least investment in new engineered works.

---

[21]Corps 1995b, B, 3D-25.

[22]Andrew Brookes, *Channelized Rivers: Perspectives for Environmental Management* (Chichester: John Wiley & Sons, 1988), 232. Note, however, that Brookes generally advocates controlled, engineered restorations; see Andrew Brookes, "Restoring the Sinuosity of Artifically Straightened Stream Channels," *Environ. Geol. Water Sci.* 10: 1 (1987): 33–41.

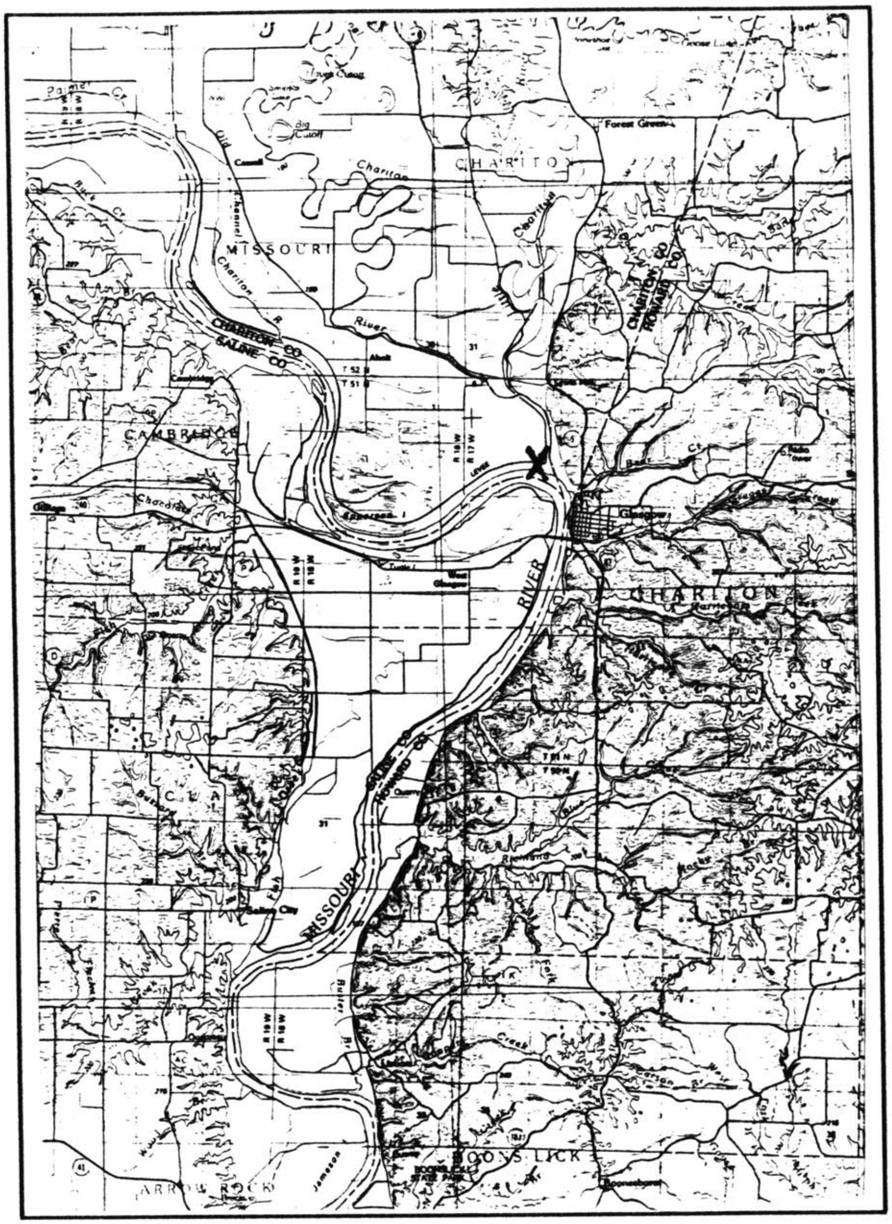
With those criteria, I have identified several key stages in and sites for restoration. I suggest that the restoration:

Capitalize on the changes wrought by the flood. Where not done already as part of levee and bank reconstruction, the scour holes, erosion scars, and chutes created by blowouts in the 1993 and 1995 floods should not be filled or cut off from the river. These areas can provide floodwater storage, especially as native vegetation returns; critical off-channel habitat for fish; and important nesting, rearing, and resting spots for migrating birds like blue and snow geese, Canada geese, mallards, redwing blackbirds, killdeer, and great blue herons.[23] Keeping chutes open may require pulling out wing dikes that trap sediments that will block the entrances.

Focus on places where the river is already trying to change its channel. It took 750 tons of rock to keep the river from changing course three miles west of Glasgow, Missouri, when the levee blew (figure 17).[24] The river also repeatedly knocks out the nonfederal levee near St. Charles, and during the 1993 flood cut across the peninsula along an old channel bed, through Portage des Sioux, to join the Mississippi (figure 18).[25] At the height of the flood, approximately 50 percent of the Missouri River's water flowed over the peninsula, at a depth of 20 feet, and buried three Missouri towns.[26] Similar crossover flow occurred in the same area during the 1973 and 1986 floods, indicating that the Missouri River, whose elevation at St. Charles is approximately 12 feet higher than the Mississippi at Portage des Sioux, is seeking a steeper slope.[27] It makes sense to plan for a changed course in these two spots: maintaining the levee system is apparently futile and not cost-effective, and, especially in the sparsely populated farmland of the peninsula, the permanent infrastructure in the river's path could be moved rather than continuously rebuilt in the same location.

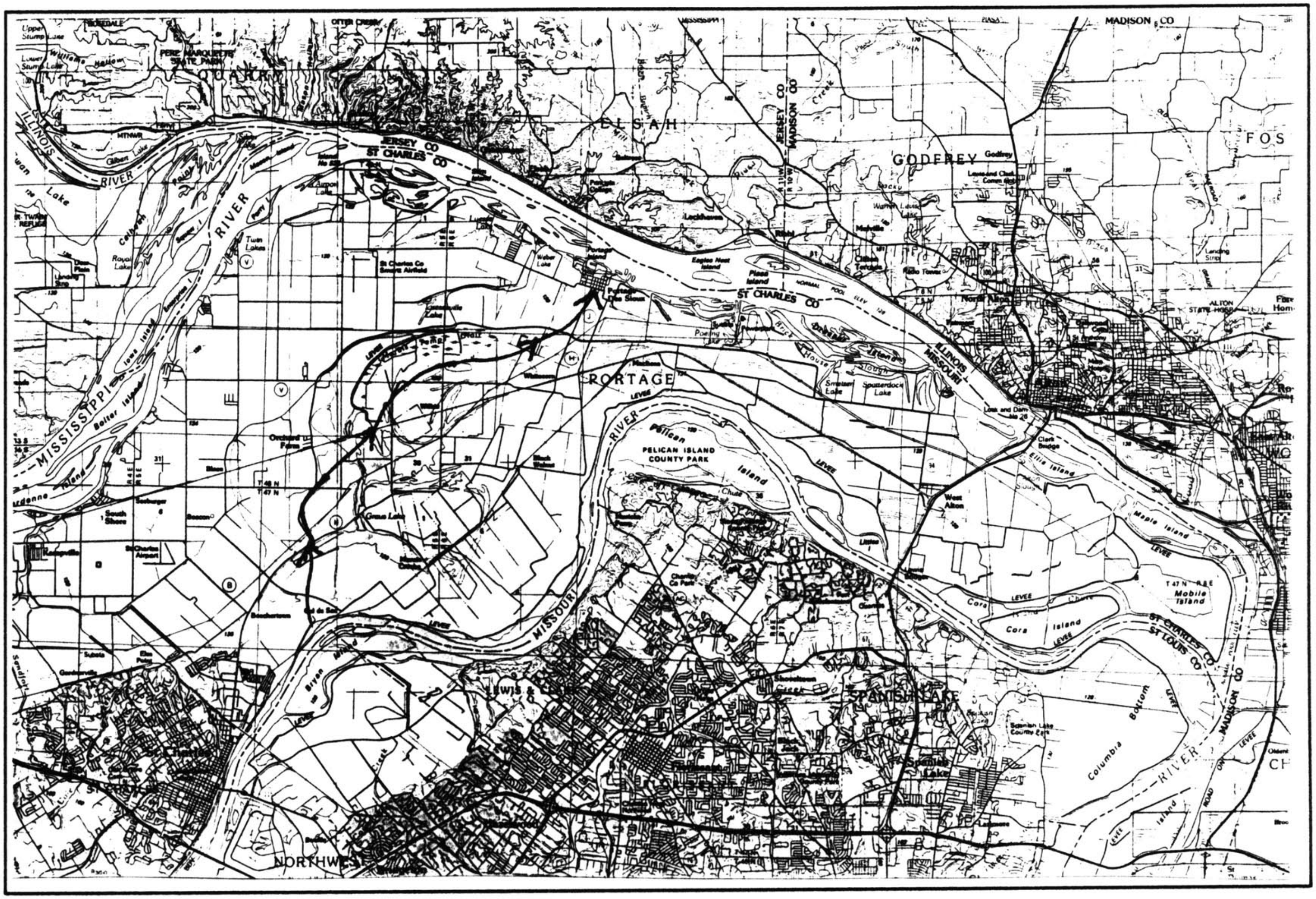
---

[23]SAST 1994, 134.
[24]Corps 1994, E, 10.
[25]Ibid.
[26]Nani G. Bhowmik, "Physical Effects: A Changed Landscape," in Stanley A. Changnon, ed., *The Great Flood of 1993: Causes, Impacts, and Responses* (Boulder, CO: Westview Press, 1996), 95, 119.
[27]Ibid., 119.



17 Current course of the Missouri River near Glasgow, and site of levee failure, July 15, 1993 (USGS)

18 (Next page) Current course of the Missouri River near St. Charles, and site of levee failure and crossover flow, July 16, 1993 (USGS)


MADISON CO
PERE MARQUETTE STATE PARK
QUARRY
ELSAH
GODFREY
FOS
JERSEY CO
ST CHARLES CO
MADISON CO
ILLINOIS RIVER
MISSISSIPPI RIVER
MISSOURI RIVER
PORTAGE
PELICAN ISLAND COUNTY PARK
Pelican Island
ST CHARLES CO
ILLINOIS
MISSOURI
Twin Lakes
Royal Lake
West Alton
Mobile Island
Cora Island
ST LOUIS CO
Columbia Bottom
SPANISH LAKE
Spanish Lake
LEWIS &
NORTHWEST
LEVEE
RIVER

Dismantle the navigation channel. For two reasons, I recommend a phased deconstruction of the wing dikes and stone revetments beginning with the first "improvement" below Gavins Point Dam and working down the river toward St. Louis. First, that sequence would strategically widen the channel and floodway to accommodate large flows from the major tributaries—the Big and Little Sioux rivers join the Missouri at Sioux City, the Platte River enters just below Omaha, and the Kansas River merges at Kansas City. Second, the floodplain from the dam to Kansas City offers considerable room for landscape changes, such as the restoration of important wetlands at the confluences to absorb overbank flow and protect the major cities downstream.[28] Though narrow just below the dam, the floodplain soon widens to between 10 and 15 miles from just above Sioux City to Omaha, is up to 10 miles wide in the reach to Rulo, Nebraska, and then narrows to approximately 3 miles as it approaches Kansas City.[29] Clearly, it would be important to stage the uprooting of wing dikes (and reconfiguration of levees) to coincide with buyouts and landscape restorations so that spreading floodwaters pose minimal threat to the populace.

Abandon the agricultural levees on the river's edge. Agricultural levees, built by a levee district's landowners with permission of the Corps of Engineers, are not required to meet federal standards and must generally be designed for only a 25-year flood. They frequently fail, therefore, and in any case cause more flood damage than they prevent by instilling a false sense of security and by concentrating flows against the federal levees.[30] Furthermore, in protecting floodplain agriculture, which would actually benefit from periodic flooding, they endanger the small town and urban populations downstream by raising flood heights.

Removing the levees does, of course, involve a trade-off. The elimination of all agricultural levees between Rulo and the confluence would

---

[28]See William J. Mitsch and James C. Gosselink, *Wetlands*, 2nd ed. (New York: Van Nostrand Reinhold, 1993), 52.
[29]Data from Corps 1995b, C, 3-1ff.
[30]It is worth noting that the Missouri Coalition for the Environment is challenging the constitutionality of the levee districts on the grounds that residents other than landowners have no representation; interview with Roger Pryor.

expose an additional 15,900 acres of crops to flooding, yet as many as six communities would be spared entirely, and other communities would experience a 7 to 10 percent reduction in residential and other urban flood damages.[31] If many of the affected farmers choose to take their land out of production rather than risk farming in periodically flooded areas, removing the levees has the added benefit of contributing significant acreage to the rebirth of forested and nonforested wetlands.[32] Furthermore, the Corps' models indicate that removing the agricultural levees would prevent overtopping, and the subsequent incision by gullies, of the federal levees in an event like the 1993 flood and thus would reduce both crop and soil damage and infrastructure repairs.[33] There is, of course, no reason to spend money to tear down the levees, since several mid-size floods will simply wash them away.

Reconfigure the federal levees over time as they need repair or replacement, with the goal of widening the floodway and gaining a broader riparian habitat zone. After the 1993 flood, the Corps realigned most of the damaged federal levees by pulling them back 750 feet from the edge of new scour holes. The now unprotected land—a total of 2,500 to 3,000 acres in the stretch between Kansas City and St. Louis—remains in private hands, but the land use has changed from agriculture to natural habitat.[34] Even with those new setbacks, however, only above Kansas City does the federal levee system conform to the requirements of the Pick-Sloan plan, which called for a floodway between 3,000 and 5,000 feet wide. Those changes are a first step, however; still needed are levees designed as "fences" around critical facilities to deflect water, rather than as walls to separate the river and the land. That design flexibility becomes especially important as the freed river recarves its course: the levees should not impede the lateral movement of the river as it roams across the floodplain, and predicting the one correct setback from a dynamic river would be difficult. Finally, I am not advocating dismantling the more complex infrastructure that protects the cities, but rather suggesting that continually

---

[31]Corps 1995b, MR, 9-8.
[32]Ibid., 9-9.
[33]Ibid., 9-13.
[34]Corps 1995 b, B, 3G-18.

raising the levees and flood walls and adding new federal levees in response to damage in settled areas is the wrong, and arguably counterproductive, approach.

Establish a buffer zone on each side of the river with wetlands and riparian vegetation for storing and desynchronizing floodwaters and for new habitat. Estimates of the amount of water wetlands store in storm events of different magnitudes vary widely, yet most sources agree that the loss of both upstream and riparian wetlands has increased flood heights throughout the nation's river and stream systems. Optimistic claims that the lost wetlands in the basin would have held the entire amount of water in excess of normal bank-full discharge[35] are balanced by cautious statements that in one postflood watershed study, "the maximum reduction for floodplain wetlands was 6 percent of the peak discharge for the 1-year event and 3 percent of a 25- and 100-year storm event."[36] Combined with other land treatment measures, such as maximizing infiltration on farmlands, however, wetland restoration could achieve runoff reductions of 12 to 18 percent for a 25-year storm and peak flood reductions of 25 to 50 percent for a flood with a return of 2 to 5 years.[37] Without the constricting levees, furthermore, floodwaters that do exceed the capacity of the buffer and hit the cropland beyond will be slower and spread horizontally, carry less sand, and cause less destruction in the form of scours and erosion scars.

The width of the buffer zone depends on several factors, including the ability to acquire floodplain lands from their owners. Clearly, the flood control benefit increases with the width, as the denser native vegetation effectively intercepts and then transpires rainwater and also captures and slows runoff and overbank flow. Although there is little information on the optimal width of bankside vegetation for preventing erosion, one study

---

[35]Donald L. Hey and Nancy S. Philippi, "Flood Reduction through Wetland Restoration: The Upper Mississippi River Basin as a Case History," *Restoration Ecology* 3: 1 (March 1995): 13.
[36]Galloway 1994, 47; see also SAST 1994, 150–62.
[37]Ibid., and Corps 1995b, MR, 8-29.

"found a correlation between buffer width and bank stability," while another found a vegetated buffer of 30 meters sufficient for controlling erosion.[38]

The scientific literature suggests that a buffer riverward of the federal levees, set back to the specified 1,500 foot minimum, would achieve the ecological objectives of a floodplain and channel restoration. In sum:

- Much of the literature on riparian buffers indicates that 100 meters, or approximately 330 feet, on each side of the river are sufficient for restoration of most ecological processes. Large and Petts (1994) note that riparian zones, whether forest or grassland, are particularly effective at improving the quality of water coming off upland agricultural lands and can reduce sediment-bound phosphorous and nitrogen inputs to streams by 80 to 87 percent and ground water nitrate inputs by more than 90 percent.[39] Most studies, they state, recommend 15 to 80 meter buffers both for that purpose and for sediment control; Binford and Buchenau (1993) suggest that a buffer of 80 to 100 meters would reduce sediment loads by 50 to 75 percent.[40]
- The recommended buffer widths for wildlife habitat range from 10 to 200 meters. Several studies demonstrate that bird species diversity increases with the increasing width of the buffer, but that 10 to 200 meters are sufficient habitat for breeding bird communities. Mammal, reptile, and amphibian species concentrate within 60 meters of the edge of the stream, but the recommended buffer is 200 meters.[41] A streamside forested buffer of as little as 10–15 meters will benefit fish, by providing

---

[38]A. R. G. Large and G. E. Petts, "Rehabilitation of River Margins," in Peter Calow and Geoffrey E. Petts, eds., *The Rivers Handbook: Hydrological and Ecological Principles* (Oxford: Blackwell Scientific Publications, 1994), vol. 2, 408.

[39] Ibid., 402.

[40]Binford and Buchenau, "Riparian Greenways and Water Resources," 93. See also Lena B.-M. Vought, et al., "Structure and function of buffer strips from a water quality perspective in agricultural landscapes," *Landscape and Urban Planning* 31 (1995): 323–331; and J.R. Cooper, et al., "Riparian Areas as Filters for Agricultural Sediment," *Soil Science Society of America Journal* 51: 2 (March–April 1987): 416–20.

[41]Large and Petts, "Rehabilitation of River Margins," 406–8. Note that most of this information comes from a table on p. 406 that summarizes the current research on the recommended width for riparian buffers. I have reviewed most of the literature, and the citations are included in the "Sources" section of this thesis.

shade, nutrients, and, through fallen branches, the riffle-pool sequences they require.[42]

Discussion. The first two recommendations essentially acknowledge the river's attempts to break free from the manmade constraints and regain a natural course. The rest aim at reconnecting the river and its floodplain to initiate the process of hydrological restoration upon which both nonstructural flood management and ecosystem recovery depend. At present, the Corps of Engineers regulates the water level in the navigation channel through controlled releases from the upstream reservoirs. As a result, the natural hydrograph, characterized by seasonal fluctuations with a wide range in amplitude and flushing flows (bank-full or dominant discharge) every 1.5 years, has been replaced by a measured flow that eliminates peaks, prevents seasonal flooding, and produces a uniform flow in the navigation channel during the April through November shipping season.[43] Recently, the Corps agreed to introduce some seasonal fluctuation to assist in the recovery of fish populations, but maintaining the navigation channel at design depth remains its highest priority.

Eliminating the navigation works, however, renders such careful flow regulation unnecessary. Furthermore, the recovery of wetlands and riparian buffer zones makes preventing moderate annual flooding to protect near-shore land uses less important as well. These recommendations, therefore, lay the groundwork for an incremental return to a natural, rather than engineered, hydrograph in the lower Missouri river. While upstream demands and retention of water in reservoirs for both recreation and hydropower purposes may prevent a full restoration of the precontrol flow

---

[42]Ibid.; see also the thorough study by David R. Barton, William D. Taylor, and R.M. Biette, "Dimensions of Riparian Buffer Strips Required to Maintain Trout Habitat in Southern Ontario Streams," *North American Journal of Fisheries Management* 5 (1985): 364–78.

[43]Larry W. Hesse and Gerald E. Mestl, "An Alternative Hydrograph for the Missouri River Based on the Precontrol Condition," *North American Journal of Fisheries Management* 13 (1993): 362; see also Larry W. Hesse, Gerald E. Mestl, and John W. Robinson, "Status of Selected Fishes in the Missouri River in Nebraska With Recommendations for Their Recovery," in Hesse, et al., eds., *Restoration Planning for the Rivers of the Mississippi River Ecosystem*, Biological Report 19 (Washington, DC: US Department of the Interior, National Biological Survey, 1993), 336–37.

and timing, it should be possible to achieve the 75 percent threshold upon which restoration of the natural flood pulse depends.[44]

In the long run, a successful restoration of a natural flood pulse is essential for recovery of the functions of a large river system. Once the structural barriers between the river and its floodplain are gone, fluctuations in the hydrograph will gradually alter the morphology and thus the hydraulics of the channel and induce the formation of the diverse habitats upon which both terrestrial and aquatic species depend. The abundant literature on the relation between flood pulse or natural disturbance regime and the richness, diversity, and resilience of lotic ecosystems comes down to one key principal: "regular flood pulses enhance productivity in both the floodplain and main channel."[45]

Over time, therefore, the predictable annual flooding restores both the river and the landscape. Rehabilitation of large river systems is in its infancy, but experience with smaller streams suggest that, left to its own devices, the lower Missouri River will tend toward a its pre-engineered dynamics. Without continued maintenance, for example, the straightened and shortened Big Pine Creek in Indiana returned to its original meandering state over a period of 40 years.[46] It took only 30 years for the Chariton River in Missouri to "revert from the uniform width and depth of the constructed channel back to natural conditions with meanders and a corresponding improvement in fish populations."[47] Other studies suggest that the "relaxation time," the "period between the commencement and the attainment of a new state of equilibrium," can be as little as 9 to 15 years on

---

[44]Hesse and Mestl, "An Alterative Hydrograph for the Missouri River," 364.

[45]Barry L. Johnson, William B. Richardson, and Teresa J. Naimo, "Past, Present, and Future Concepts in Large River Ecology," *BioScience* 45: 3 (March 1995): 136. Note that this issue of *BioScience* is devoted to the ecology of large rivers; it plus a similar special issue *Environmental Management* 14: 5 (September–October 1990) effectively present the current research in the field of ecology and restoration of river systems. See also the two-volume *The Rivers Handbook*, ed. Calow and Petts.

[46]Brookes, *Channelized Rivers*, 93.

[47]Andrew Brookes, "River Channel Change," in Calow and Petts, eds., *The Rivers Handbook*, vol. 2, 67; he cites a study by J.C. Congdon, "Fish Populations of Channelized and Unchannelized Sections of the Chariton River, Missouri," in E. Schneberger and J.L. Funk, eds., *Stream Channelization: A Symposium*. Special Publication 2 (Bethesda: North Central Division, American Fish Society, 1971).

small rivers, with substantial recovery of fish populations in 30 to 86 years.[48] Those numbers suggest that it is realistic to envision a recovery of the lower Missouri River over 50 to 75 years and to take the first steps toward the policies and plans that will set the river free.

Planning for Change

Older configurations of the river, most notably the 1879 survey, hint at what the freed river could become if "left to its own devices" (figure 19).[49] But the imprint of more than a century of intervention will remain, and as long as the dams still stand, the river will not again be the Big Muddy of old.

Most river restoration is done on small streams with as much engineering as the original channelization, so there is no precedent from which to predict the shape and behavior of a freed Missouri River. The literature focuses on engineering principles—not natural processes—for restoring sinuosity and gives all the equations for recreating the original cross-section dimensions, slope, and substrate of the channel.[50] We know, for instance, that sediment size and quantity determine both the morphology and the primary physical habitat of river channels.[51] We also know that the lower

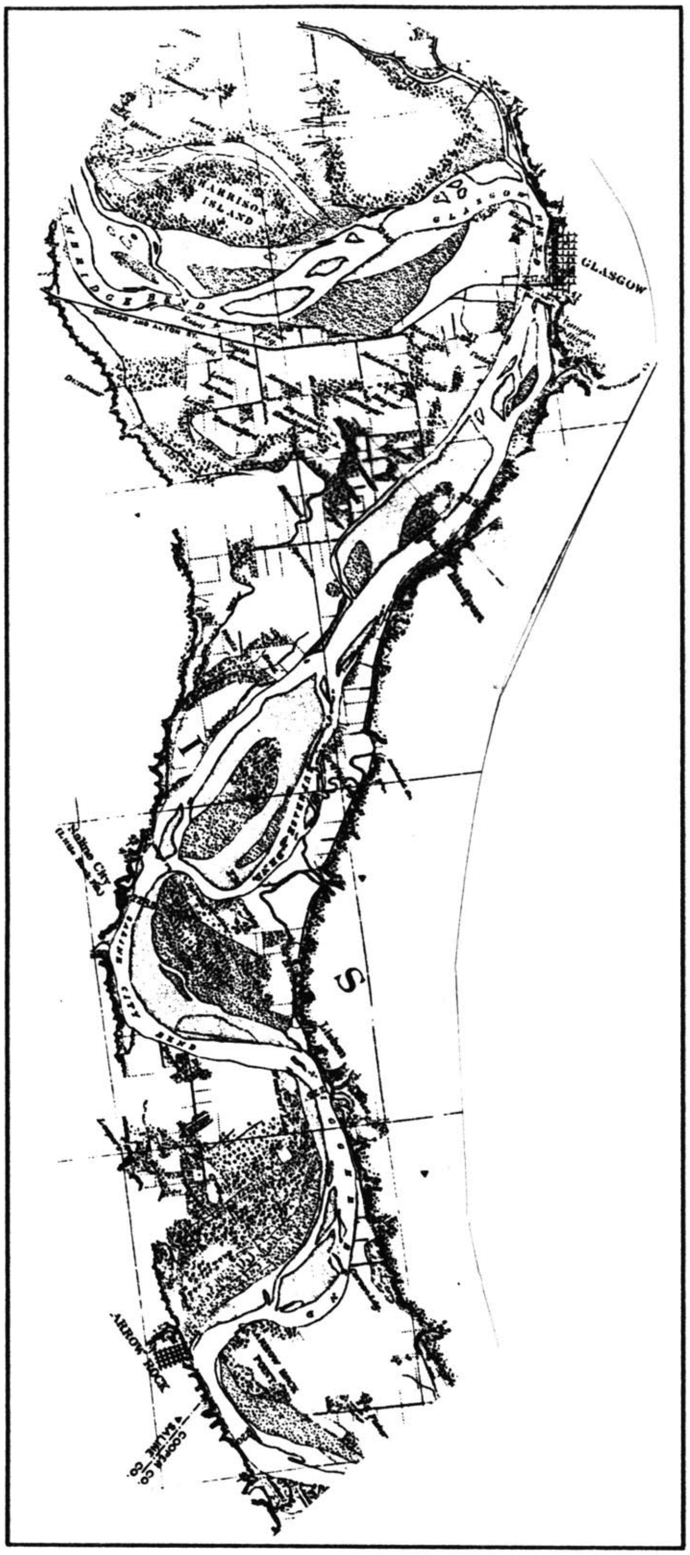
---

[48]Ibid., 71, citing several studies. For an examination of the complex physical and biological factors affecting recovery time, see also A.M. Milner, "System Recovery," in Calow and Petts, eds., *The Rivers Handbook*, vol. 2, 76–97; James A. Gore and Alexander M. Milner, "Island Biogeographical Theory: Can It Be Used to Predict Lotic Recovery Rates?" *Environmental Management* 14: 5 (September–October 1990): 737–53; and James A. Gore and F. Douglas Shields, Jr., "Can Large Rivers Be Restored?" *BioScience* 45: 3 (March 1995): 142–52.

[49]The hand-drawn maps from the 1879 survey are extremely informative and beautiful, but are unfortunately too large to reproduce in this format. For comparisons of the river over time, see the extended series of drawings in John L. Funk and John W. Robinson, *Changes in the Channel of the Lower Missouri River and Effects on Fish and Wildlife*. Aquatic Series 11 (Jefferson City: Missouri Department of Conservation, 1974); the drawings and graphs in W. Carter Johnson, et al., *Altered Hydrology of the Missouri River and Its Effects of Floodplain Forest Ecosystems* (Blacksburg: Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, 1982); and the SAST database.

[50]See, for example, Brookes, "Restoring the Sinuosity of Artificially Straightened Stream Channels"; P. Larsen, "Restoration of River Corridors: German Experiences," in Calow and Petts, eds., *The Rivers Handbook*, vol. 2, 419–37; and James A. Gore and Franklin L. Bryant, "River and Stream Restoration," in John Cairns, Jr., ed., *Rehabilitating Damaged Ecosystems* (Boca Raton: CRC Press, Inc., 1988), vol. 1, 23–38.

[51]See, for example, Gore and Shields, "Can Large Rivers Be Restored?", 144; M. Church, "Channel Morphology and Typology," in Calow and Petts, eds., *The Rivers Handbook*, vol. 1, 126–43; and R. Bettess, "Sediment Transport and Channel Stability," in Calow and Petts, eds., *The Rivers Handbook*, vol. 2, 227–53.



19 The Missouri River near Glasgow, 1879 (Courtesy Library of Congress)

Missouri River carries approximately a quarter of the original suspended sediment load and that the mixture of sand to silt and clay is reversed.[52] What we cannot know, with any certainty, is how the combination of sediment trapped behind the dams upstream and erosion of the bed and banks with the restoration of a natural flood pulse will affect the sediments carried by the freed river. We can crunch all the "what if" numbers and come up with a range, but in the end we can only speculate about how sediment transport will affect the meandering and braiding of the river, the formation of sand bars and small islands, and the recovery of a "natural" width and depth.

Removing the structural restraints does indeed revive the historical uncertainty about where the river will go, but during the gradual rehabilitation, we will have decades to watch the river and to learn. Our best guide for the master plan is the historical record, which shows how the river recarves the floodplain, how its meanders occupy the land both vertically and horizontally, and how the braids envelope small, unstable pieces of the landscape and create new, if ephemeral, habitat. From those clues, we can plan the configuration of land uses in the basin to remove from the river's path those activities most vulnerable to its vagaries. Ultimately, the successful restoration of a natural regime on the lower Missouri Rivers rests on our ability to adapt our settlement patterns to the unpredictability of a dynamic system rather than asking it to yield to us. For learning to live with shifting boundaries and a different cycle of risk, we will be rewarded with the prospect of a healthy "river meandering the open and butifull Plains"

---

[52]Prior to the dams and navigation works, the sediment load was approximately 20–30 percent sandy bed material and 70–80 percent silt and clay wash load: the proportions are now reversed (Corps 1994, D, 29).

ABBREVIATIONS FOR WORKS FREQUENTLY CITED

Corps 1994. US Army Corps of Engineers. *The Great Flood of 1993. Post-Flood Report.* Main Report (MR) plus 5 volumes (A–E) of regional reports. September 1994.

Corps 1995a. US Army Corps of Engineers. *Floodplain Management Assessment. Draft Report.* Main Report (MR) plus 5 volumes (A–E) of technical appendices. March 1995.

Corps 1995b. US Army Corps of Engineers. *Floodplain Management Assessment. Final Report.* Main Report (MR) plus 5 volumes (A–E) of technical appendices. June 1995.

Galloway 1994. Interagency Floodplain Management Review Committee. *Sharing the Challenge: Floodplain Management into the 21st Century.* Washington, DC, June 1994.

MBIAC 1971. Missouri Basin Inter-Agency Committee. *The Missouri Basin Comprehensive Framework Study.* 7 vols. June 1969 (published December 1971).

SAST. Scientific Assessment and Strategy Team, US Geological Survey Eros Data Center, Web site, http://edc.www2.cr.usgs.gov/sast_home.html.

SAST 1994. Scientific Assessment and Strategy Team. *Science for Floodplain Management into the 21st Century.* Washington, DC, June 1994.

SOURCES

Interviews

Al Austin, Department of Civil Engineering, Iowa State University, April 1994.

Anna Crickmer, US Army Corps of Engineers, Emergency Management Division, Omaha, April 1994.

Dan Dickneite, Chief of Planning Division, Missouri Department of Conservation, Jefferson City, March 1996.

Wayne Fischer, US Fish and Wildlife Service, Illinois, April 1994.

Greg Gremaud, Natural History Lands Coordinator, Missouri Department of Conservation, Jefferson City, March 1996.

Dick Heidebrecht, US Army Corps of Engineers, Planning Directorate, Basin Management Division, Waltham, MA, April 1994.

Constance Hunt, Senior Program Officer, World Wildlife Fund, Washington, DC, April 1994.

Jon Kusler, Executive Director, Association of State Wetland Managers, Berne, NY, September 1994.

David Loss, US Army Corps of Engineers, St. Paul, MN, April 1994.

Roger Pryor, Director, Missouri Coalition for the Environment, St. Louis, March 1996.

Harry Shoudy, US Army Corps of Engineers, Washington, DC, April 1994.

Maps, Satellite Images, and Data

Missouri River Basin Commission and Missouri Basin States Association. *Atlas of Flood Plain Land Use and Land Cover of the Lower Missouri River Basin.* 130 map sheets. 1982.

Missouri River Commission. *Map of the Missouri River, from its mouth to Three Forks, Montana.* 84 map sheets and 9 index sheets. 1892–95 (from 1878–92 survey). Courtesy Library of Congress.

Scientific Assessment and Strategy Team, US Geological Survey Eros Data Center, Web site, http://edc.www2.cr.usgs.gov/sast_home.html.

Literature

Missouri River Basin

Ambrose, Stephen E. *Undaunted Courage: Meriwether Lewis, Thomas Jefferson, and the Opening of the American West.* New York: Simon & Schuster, 1996.

Barry, John M. *Rising Tide: The Great Mississippi Flood of 1927 and How It Changed America.* New York: Simon & Schuster, 1997.

Botkin, Daniel B. *Our Natural History: The Lessons of Lewis and Clark.* New York: G. P. Putnam's Sons, 1995.

Boundaries Carved in Water. Missoula, MT: Missouri River Management Project, Northern Lights Research and Education Institute, 1988.

Bragg, T. B., and A. K. Tatschl. "Changes in Flood-plain Vegetation and Land Use Along the Missouri River from 1826 to1972." *Environmental Management* 1:4 (1977): 343–48.

Ferrell, J. R. *Big Dam Era: A Legislative History of the Pick-Sloan Missouri River Basin Program.* Omaha: US Army Corps of Engineers, Missouri River Division, 1993.

Floods of April 1952 in the Missouri River Basin. Washington, DC: US Geological Survey, 1955.

Foster, Charles H. W. "Regionalism and the Missouri River Basin: A New England Perspective." Paper delivered at the Missouri River Assembly, Bismarck, ND, June 3–5, 1990.

Frederickson, L. H. *Floral and Faunal Changes in Lowland Hardwood Forests in Missouri Resulting from Channelization, Drainage, and Improvement.* FWS Report OBS-78/91. US Fish and Wildlife Service, 1979.

Funk, John L., and John W. Robinson. *Changes in the Channel of the Lower Missouri River and Effects on Fish and Wildlife.* Aquatic Series 11. Jefferson City: Missouri Department of Conservation, 1974.

General Accounting Office. "Report to Congressional Requesters, Water Resources, Corps' Management of Ongoing Drought in the Missouri River Basin." GAO/RCED-92-4 Drought Management, 1992.

Graham, Bill. "Restoring Nature to the Missouri." *The Kansas City Star,* Thursday, March 28, 1996, A1, A4.

Hart, Henry C. *The Dark Missouri.* Madison: University of Wisconsin Press, 1957.

Hedman, E. R., and D. G. Jorgensen. "Surface- and Ground-water Interaction and Hydrologic Budget of the Missouri River Valley Aquifer Between Yankton, South Dakota, and St. Louis, Missouri." *Hydrologic Investigations Atlas.* US Department of the Interior, US Geological Survey, 1990.

Hesse, L. W., and G. E. Mestl. "An Alternative Hydrograph for the Missouri River Based on the Precontrol Condition." *North American Journal of Fisheries Management* 13:2 (Spring 1993): 360–66.

Hesse, L. W., and J. C. Schmulbach. "The Missouri River Basin: The Great Plains Thread of Life." Paper delivered at the Missouri River Assembly, Bismarck, ND, June 3–5, 1990. Subsequently published in *Boundaries Carved in Water: The Missouri River Brief Series* 16. Missoula: Northern Lights Institute, April 1991.

Hesse, L. W., and W. Sheets. "The Missouri River Hydrosystem." *Fisheries* 18:5 (May 1993): 5–14.

Hesse, L. W., et al., eds. *Restoration Planning for the Rivers of the Mississippi River Ecosystem.* Biological Report 19. Washington, DC: US Department of the Interior, National Biological Survey, 1993.

Hicks, Orville. "Reservations and Water." Paper delivered at the Missouri River Assembly, Bismarck, ND, June 3–5, 1990.

Johnson, W. Carter. "Dams and Riparian Forests: Case Study from the Upper Missouri River." *Rivers* 3:4 (1992): 229–42.

———. "Divergent Responses of Riparian Vegetation to Flow Regulation on the Missouri and Platte Rivers." In Larry W. Hesse, et al., eds., *Restoration*

Planning for the Rivers of the Mississippi River Ecosystem. Biological Report 19. Washington, DC: US Department of the Interior, National Biological Survey, 1994.

Johnson, W. Carter, Peggy W. Reily, L. Scott Andrews, James F. McLellan, and John A. Brophy. *Altered Hydrology of the Missouri River and Its Effects on Floodplain Forest Ecosystems.* Bulletin 139. Blacksburg: Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, 1982.

Keyser, C. Frank. *Missouri Valley Authority: Background and Analysis of Proposal (S. 555, 79th Cong.). Public Affairs Bulletins* 42. Washington, DC: The Library of Congress Legislative Reference Service, 1946.

Langer, William H., Constance K. Throckmorton, and Steve P. Schilling. *Earth Science Issues in the Missouri River Basin: Man's Adaptation to the Changing Landscape.* US Geological Survey, Open File Report 94-195, 1994.

Lewis, Meriwether, and William Clark. *The History of the Lewis and Clark Expedition.* Edited by Elliott Coues. Reprint in 3 vols. of the 4-vol. 1893 edition. New York: Dover Publications, Inc., n.d.

———. *The Journals of Lewis and Clark.* Edited with an introduction by Bernard DeVoto. 1 vol. abridged edition. New York: Houghton Mifflin Company, 1953.

Mickelson, George S. "My View of the Missouri River." *University of South Dakota Law Review* 36:1 (1991): 1–7.

Missouri Basin Inter-Agency Committee. *The Missouri River Basin Comprehensive Framework Study.* 7 vols. Completed June 1969. Washington, DC: GPO, 1971.

Missouri Department of Conservation. "Endangered Species in Missouri." Jefferson City, 1995.

———. "Enjoying the Wide Missouri: The Missouri River Recreation Survey." Jefferson City, 1990.

———. "Fishing Prospects at Selected Missouri Lakes and Streams." Jefferson City, 1996.

———. *Missouri Conservationist: Big Rivers Special Issue* (August 1995).

———. "Vision Statement and Commission Recommendation." October 27, 1995.

Missouri Department of Natural Resources. *The Missouri Flood Model: A Working Model That Demonstrates the Forces at Work When a River Floods.* Jefferson City, 1990.

Mueller, Gerald. "The Northwest Power Planning Council: A Model for Cooperative Planning in the Missouri Basin?" Paper delivered at the Missouri River Assembly, Bismarck, ND, June 3–5, 1990.

Nestler, John M. *Physical Habitat Analysis of Missouri River Main Stem Reservoir Tailwaters Using the Riverine Community Habitat Assessment and Restoration Concept (RCHARC).* Vicksburg, MS: US Army Corps of Engineers, Waterways Experiment Station, 1993.

Pierce, Don. *Exploring Missouri River Country.* Jefferson City: Missouri Department of Natural Resources, Division of Parks and Historic Preservation, n.d. (early 1980s).

Pflieger, William, and Lawrence C. Belusz. "An Introduction to Missouri Fishes." Jefferson City: Missouri Department of Conservation, 1982.

Rafferty, Milton D. *Historical Atlas of Missouri.* Norman: University of Oklahoma Press, 1982.

Ragan, Mark Lawrence. "Uncle Sam Tries to Part the Waters." *Insight* (June 25, 1990): 26–28.

Schmudde, T. H. "Some Aspects of Land Forms of the Lower Missouri River Floodplain." *Annals of the Association of American Geographers* 53 (1963): 60–73.

Serda, Daniel. *A Blow to the Spirit: The Kaw River Flood of 1951 in Perspective.* Kansas City, MO: Midwest Research Institute, October 28, 1993.

Thorson, John E. *River of Promise, River of Peril: The Politics of Managing the Missouri River.* Lawrence: University Press of Kansas, 1994.

US Army Corps of Engineers. *Effects on Flood Heights of Levee, Railroad, and Highway Fills in the Flood Plain of the Missouri River: Hydraulic Model Investigation.* Vicksburg: US Army Corps of Engineers, Waterways Experiment Station, 1955.

———. *Missouri River: Riverine Habitat and Floodway Restoration Program: Status of the Construction.* Omaha, 1975.

———. *Riverine Habitat and Floodway Restoration: Missouri River, Sioux City, Iowa to the mouth near St. Louis, Missouri. An Evaluation of the Notched Structures in Creating Additional Backwater Areas.* Omaha, 1982.

US Department of the Interior, Bureau of Reclamation. *Missouri River Basin: Conservation, Control, and Use of Water Resources of the Missouri River Basin in Montana, Wyoming, Colorado, North Dakota, South Dakota, Nebraska, Kansas, Iowa, and Missouri. Report by Secretary of the Interior Harold L. Ickes on Bureau of Reclamation's Plan for Basin Development.* Washington, DC: 78th Congress, 2d Session. Senate Document 191, April 1944.

———. *Putting the Missouri to Work.* Washington, DC, July 1, 1945.

The 1993 Flood and the Postflood Response

Allen, William H. "The Great Flood of 1993." *BioScience* 43:11 (December 1993): 732–37.

Association of State Wetland Managers. "Summary, Conclusions and Recommendations. State/Federal Technical Workshop, Identifying Potential Post Flood Floodplain/Wetland Restoration Sites for the Mississippi Basin (Including the Missouri and Other Tributaries)." Workshop in St. Louis, January 13–14, 1994.

———. *Post Flood Response and The Restoration of Wetlands, Riparian Areas, and Broader Floodplains. Sourcebook of Materials.* Berne, NY, 1994.

———. "Restoration of Aquatic Ecosystems: A Proposed Action Agenda." May 1994.

Changnon, Stanley A., ed. *The Great Flood of 1993: Causes, Impacts, and Responses.* Boulder: Westview Press, 1996.

Curley, Anne, and Randy Urich. "The Flood of '93: An Ecological Perspective." *Journal of Forestry* 91:9 (September 1993): 28–30.

Denning, James. "When the Levee Breaks." *Civil Engineering* (January 1994): 38–41.

Dohrenwend, J. C., et al. "Flood Flow Characteristics of the 1993 Missouri River Flood Determined from Flood Plain Erosion and Deposition, Kansas City to St. Louis." *EOS* 75:15, American Geophysical Union Annual Transactions (1994).

Faber, Scott. "Letting Down the Levee." *Urban Land* (March 1994): 25–27.

Freshwater Foundation/McKnight Foundation. "The State of the Upper Mississippi River: From the Headwaters to the Quad Cities." Interim Report, March 1994.

Goolsby, Donald A., William A. Battaglin, and E. Michael Thurman. *Occurrence and Transport of Agricultural Chemicals in the Mississippi River Basin, July through August 1993.* US Geological Survey Circular 1120-C, September 1993.

Hey, Donald. "Memorandum. Upper Mississippi River Wetland Restoration Project. Four-month Progress Report." The Wetlands Initiative, August 30, 1994.

Interagency Floodplain Management Review Committe. Scientific Assessment Strategy Team. *Science for Floodplain Managment into the 21st Century.* Washington, DC, June 1994.

Interagency Floodplain Management Review Committee. *Sharing the Challenge: Floodplain Management into the 21st Century.* Washington, DC, June 1994.

Kunkel, K. E., S. A. Changnon, and J. R. Angel. "Climatic Aspects of the 1993 Upper Mississippi River Basin Flood." *Bulletin of the American Meterological Society* 75 (1994): 811–22.

Myers, Mary Fran, and Gilbert F. White. "The Challenge of the Mississippi Flood." *Environment* 35:10 (December 1993): 7–9, 25–35; commentary 2–5, 36.

Parrett, Charles, Nick B. Melcher, and Robert W. James, Jr. *Flood Discharges in the Upper Mississippi Basin, 1993.* US Geological Survey Circular 1120-A, August 1993.

Perry, Charles A. *Effects of Reservoirs on Flood Discharges in the Kansas and Missouri River Basins, 1993.* US Geological Survey Circular 1120-E, 1994.

Philippi, Nancy S. "Revisiting Flood Control: An Examination of Federal Flood Control Policy in Light of the 1993 Flood Event on the Upper Mississippi River." Wetlands Research, Inc., May 1994.

Robinson, Ann, and Robbin Marks. *Restoring the Big River: A Clean Water Act Blueprint for the Mississippi.* Izaak Walton League of America and Natural Resources Defense Council, February 1994.

Shepard, R. "Floodplain Development: Lessons Learned from the Great Flood of 1993." *Urban Land* 53:3 (March 1994): 19–24, 42, 44.

Sparks, Richard E. "Introductory Remarks on the 1993 Flood on the Upper Mississippi River for the Keynote Speech: Forecast for the Upper Mississippi River." 71st National Convention of the Izaak Walton League of America, Davenport, Iowa, July 13–16, 1993.

———. "Testimony Before the House Subcommittee on Water Resources and the Environment, 27 October 1993."

———, and Ruth Sparks. "After the Flood: Restoring Ecosystems." *USA Today* (July 1994): 40–42.

Stevens, William K. "Restored Wetlands Could Ease Threat of Mississippi Floods." *The New York Times,* Tuesday, August 8, 1995, C1.

Tanenbaum, David. "Rethinking the River." *Nature Conservancy* (July–August 1994): 11–15.

Taylor, Howard E., Ronald C. Antweiler, Terry I. Brinton, David A. Roth, and John A. Moody. *Major Ions, Nutrients, and Trace Elements in the Mississippi River near Thebes, Illinois, July through September 1993.* US Geological Survey Circular 1120-D, 1994.

Tibbets, John. "Waterproofing the Midwest." *Planning* (April 1994): 8–13.

Upper Mississippi River Basin Association. *Alternative Mechanisms for Formulating an Ecosystem Strategy for the Upper Mississippi River.* St. Paul, April 1994.

———. Letter to Brigadier General Gerald E. Galloway from Holly Stoerker, Executive Director. June 6, 1994.

———. State Floodplain Management Work Group. "Recommendations to the Interagency Floodplain Management Review Committee." March 15, 1994.

Uhlenbrock, Tom. "Big Muddy: Groups to Seek Restoration of Missouri River." *St. Louis Post-Dispatch,* December 24, 1994, B, 3:1.

Upper Mississippi River Conservation Committee. "Facing the Threat: An Ecosystem Management Strategy for the Upper Mississippi River." December 1993.

US Army Corps of Engineers. "Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries. Plan of Study." April 29, 1994.

———. "Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries. 1st Milestone Package: Existing Condition Identification Summary." August 5, 1994.

———. "Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries. 2nd Milestone Package: Problem/Issue Identification Issue." September 15, 1994.

———. "Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries. 3rd Milestone Package: Alternatives Identified and Developed." January 20, 1995.

———. *Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries.* 6 vols. Draft Main Report and Technical Appendices. March 1995.

———. *Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries.* 6 vols. Final Main Report and Technical Appendices. June 1995.

———. *The Great Flood of 1993 Post-Flood Report: Upper Mississippi and Lower Missouri River Basins.* 6 vols. Main Report and Regional Appendices. September 1994.

US Department of Agriculture, Soil Conservation Service. "Assessment of Landscape Changes in the Missouri River Corridor Due to the Great Flood of 1993." January 1994.

US Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Bureau. *Natural Disaster Survey Report: The Great Flood of 1993*. Rockville, MD, 1994.

US Department of the Interior, US Geological Survey. "Technical Announcement." Reston, VA, January 10, 1995.

World Wildlife Fund. *The 1993 Mississippi River Floods: Implications for Wildlife, Wetlands, and People*. Washington, DC, 1994.

Hydrology, River System Dynamics, and Stream and Wetland Restoration

Amoros, Claude, Jean-Claude Rostan, Guy Patou, and Jean-Paul Bravard. "The Reversible Process Concept Applied to the Environmental Management of Large River Systems." *Environmental Management* 11:5 (September 1987): 607–17.

Bayley, Peter B. "Understanding Large River–Floodplain Ecosystems." *BioScience* 45:3 (March 1995): 153–58.

Belt, C. B., Jr. "The 1973 Flood and Man's Constriction of the Mississippi River." *Science* 189:4204 (29 August 1975): 681–84.

Binford, Michael W. "Methods of Evaluating Ecological Functions of Wetlands." Forthcoming in P. P. Rogers and R. llamas, eds., *Research Agenda for Wetlands: A Multidisciplinary Approach*. Draft paper, 30 pp.

Brookes, Andrew. *Channelized Rivers: Perspectives for Environmental Management*. New York: John Wiley & Sons, 1988.

———. "Restoring the Sinuosity of Artificially Straightened Stream Channels." *Environmental Geology and Water Science* 10:1 (1987): 33–41.

Calow, Peter, and Geoffrey E. Petts, eds. *The Rivers Handbook*. 2 vols. London: Blackwell Scientific Publications, 1992.

Cummins, Kenneth W. "Structure and Function of Stream Ecosystems." *BioScience* 24:11 (November 1974): 631–41.

Dawes, Warrick R., and David Short. "The Significance of Topology for Modeling the Surface Hydrology of Fluvial Landscapes." *Water Resources Research* 30:4 (April 1994): 1045–55.

DeAngelis, D. L., P. J. Mulholland, J. W. Elwood, A. V. Palumbo, and A. D. Steinman. "Biogeochemical Cycling Constraints on Stream Ecosystem Recovery." *Environmental Management* 14:5 (September–October 1990): 685–97.

Décamps, Henri, Madeleine Fortuné, François Gazelle, and Guy Patou. "Historical Influence of Man on the Riparian Dynamics of a Fluvial Landscape." *Landscape Ecology* 1:3 (1988): 163–73.

Dunne, Thomas, and Luna B. Leopold. *Water in Environmental Planning.* New York: W. H. Freeman and Company, 1978.

The Effect of Channelization on the Environment. Hearing Before the Subcommittee on Flood Control—Rivers and Harbors of the Committee on Public Works, United States Senate, Ninety-Second Congress, First Session, July 27, 1971. Washington, DC: US GPO, serial no. 92-H24, 1971.

Ewel, Katherine C. "Multiple Demands on Wetlands." *BioScience* 40:9 (October 1990): 660–66.

Fisher, Stuart G. "Recovery Processes in Lotic Ecosystems: Limits of Successional Theory." *Environmental Management* 14:5 (September–October 1990): 725–36.

Frissell, Christopher A., William J. Liss, Charles E. Warren, and Michael D. Hurley. "A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context." *Environmental Management* 10:2 (1986): 199–214.

Gore, James A., and Franklin L. Bryant. "River and Stream Restoration." In John Cairns, Jr. , ed., *Rehabilitating Damaged Ecosystems.* Boca Raton: CRC Press, Inc., 1988, 1:23–38.

Gore, James A., and Alexander M. Milner. "Island Biogeographical Theory: Can It Be Used to Predict Lotic Recovery Rates?" *Environmental Management* 14:5 (September–October 1990): 737–53.

Gore, James A., and F. Douglas Shields, Jr. "Can Large Rivers Be Restored?" *BioScience* 45:3 (March 1995): 142–52.

Gorman, Owen T., and James R. Karr. "Habitat Structure and Stream Fish Communities." *Ecology* 59:3 (Spring 1978): 507–15.

Gosselink, J. G., S. E. Bayley, W. H. Conner, and R. E. Turner. "Ecological Factors in the Determination of Riparian Wetland Boundaries." In J. R. Clark and J. Benforado, eds., *Wetlands of Bottomland Hardwood Forests: Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern US*. Amsterdam: Elsevier Scientific Publishing, 1981.

Hall, Brad R. *Impact of Agricultural Levees on Flood Hazards. Final Report.* Vicksburg, MS: US Army Corps of Engineers, Waterways Experiment Station, 1991.

Hammer, Donald A. *Creating Freshwater Wetlands*. Boca Raton: Lewis Publishers, 1992.

Harbor, Jonathan M. "A Practical Method for Estimating the Impact of Land-Use Change on Surface Runoff, Groundwater Recharge and Wetland Hydrology." *Journal of the American Planning Association* 60:1 (Winter 1994): 95–108.

Hey, Donald L. "The Des Plaines River Wetlands Demonstration Project: Restoring an Urban Wetland." In Rutherford H. Platt, Rowan A. Rowntree, and Pamela C. Muick, eds., *The Ecological City: Preserving and Restoring Urban Biodiversity*. Amherst: University of Massachusetts Press, 1994.

———, and Nancy S. Philipi. "Flood Reduction Through Wetland Restoration: The Upper Mississippi River Basin as a Case Study." *Restoration Ecology* 3:1 (March 1995): 4–17.

Hirsch, R. M., J. F. Walker, J. C. Day, and R. Kallio. "Influence of Man on Hydrologic Systems." In *Surface Water Hydrology*. Boulder, CO: Geological Society of America, 1990, pp. 329–59.

Holland, Marjorie M., and Raymond W. Prach. "Sustainability of Urban Wetlands." In Rutherford H. Platt, Rowan A. Rowntree, and Pamela C. Muick, eds., *The Ecological City: Preserving and Restoring Urban Biodiversity*. Amherst: University of Massachusetts Press, 1994.

Hunsaker, Carolyn T., and Daniel A. Levine. "Hierarchical Approaches to the Study of Water Quality in Rivers." *BioScience* 45:3 (March 1995): 193–203.

Johnson, Barry L., William B. Richardson, and Teresa J. Naimo. "Past, Present, and Future Concepts in Large River Ecology." *BioScience* 45:3 (March 1995): 134–41.

Johnston, Carol A. "Sediment and Nutrient Retention by Freshwater Wetlands: Effects on Surface Water Quality." *Critical Reviews in Environmental Control* 21:5–6 (1991): 491–565.

King, Dennis M., and Curtis C. Bohlen. "Estimating the Costs of Wetland Restoration." *National Wetlands Newsletter* 16:3 (May–June 1994): 3–8.

———. "Making Sense of Wetland Restoration Costs." University of Maryland, Center for Environmental and Estuarine Studies, January 1994.

Kusler, Jon. "Wetlands Delineation: An Issue of Science or Politics?" *Environment* 34:2 (March 1992): 7–37.

———, and Mary E. Kentula, eds. *Wetland Creation and Restoration: The Status of the Science.* Covelo, CA: Island Press, 1990.

———, William J. Mitsch, and Joseph S. Larson. "Wetlands." *Scientific American* (January 1994): 64B–70.

Latka, D. C., J. Nesler, and L. W. Hesse. "Restoring Physical Habitat in the Missouri River: A Historical Perspective." In L. W. Hesse, et al., eds. *Restoration Planning for the Rivers of the Mississippi River Ecosystem.* Biological Report 19. Washington, DC: National Biological Survey, 1993, pp. 350–59.

Leopold, Luna B. *A View of the River.* Cambridge: Harvard University Press, 1994.

Ligon, Franklin K., William E. Dietrich, and William J. Trush. "Downstream Ecological Effects of Dams: A Geomorphic Perspective." *BioScience* 45:3 (March 1995): 183–92.

Michaud, Jene. "Comparison of Simple Versus Complex Distributed Runoff Models on a Midsized Semiarid Watershed." *Water Resources Research* 30:3 (March 1994): 593–605.

Mitsch, William J., and James G. Gosselink. *Wetlands.* 2nd ed. New York: Van Nostrand Reinhold, 1993.

Nachtnebel, Hans-Peter. "Linkage Between the Hydrological and Ecological Systems in the Floodplain." In John Gardiner, Odön Starosolszky, and Vujica Yevjevich, eds., *Defence from Floods and Floodplain Management.* Boston: Kluwer Academic Publishers, 1995.

National Research Council, Committee on Restoration of Aquatic Ecosystems. *Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy.* Washington, DC: National Academy Press, 1992.

Nunnally, Nelson R., F. Douglas Shields, Jr., and James Hynson. "Environmental Considerations for Levees and Floodwalls." *Environmental Management* 11:2 (1987): 183–91.

Poff, N. LeRoy, and J. V. Ward. "Physical Habitat Template of Lotic Systems: Recovery in the Context of Historical Pattern of Spatiotemporal Heterogeneity." *Environmental Management* 14:5 (September–October 1990): 629–45.

Power, Mary E., Adrian Sun, Gary Parker, William E. Dietrich, and J. Timothy Wootton. "Hydraulic Food-Chain Models." *BioScience* 45:3 (March 1995): 159–67.

Reice, Seth R., Robert C. Wissmar, and Robert J. Naiman. "Disturbance Regimes, Resilience, and Recovery of Animal Communities and Habitats in Lotic Ecosystems." *Environmental Management* 14:5 (September–October 1990): 647–59.

Riley, Ann L. "The Greening of Federal Flood-Control Policies: The Wildcat-San Pablo Creeks Case." In Rutherford H. Platt, Rowan A. Rowntree, and Pamela C. Muick, eds., *The Ecological City: Preserving and Restoring Urban Biodiversity.* Amherst: University of Massachusetts Press, 1994.

Schlosser, Isaac J., and James R. Karr. "Riparian Vegetation and Channel Morphology Impact on Spatial Patterns of Water Quality in Agricultural Watersheds." *Environmental Management* 5:3 (May 1981): 233–43.

Sedell, James R., and Judith L. Froggart. "Importance of Streamside Forests to Large Rivers." *International Vereiningung für Theoretische und Angewandte Limnologie Verhandlungen* 22 (December 1984): 1828–34.

Sedell, James R., Gordon H. Reeves, F. Richard Hauser, Jack A. Stanford, and Charles P. Hawkins. "Role of Refugia in Recovery from Disturbances: Modern Fragmented and Disconnected River Systems." *Environmental Management* 14:5 (September–October 1990): 711–24.

Sowl, J. H. "Restoration of Riparian Wetlands Along a Channelized River: Oxbow Lakes and the Middle Missouri." In John J. Berger, ed., *Environmental Restoration: Science and Strategies for Restoring the Earth.* Covelo, CA: Island Press, 1990.

Sparks, Richard E., Peter B. Bayley, Stephen L. Kohler, and Lewis L. Osborne. "Disturbance and Recovery of Large Floodplain Rivers." *Environmental Management* 14:5 (September–October 1990): 699–709.

Tajchman, S. "Evapotranspiration and Energy Balances of Forest and Field." *Water Resources Research* 7 (1971): 511–23.

Yount, J. David, and Gerald J. Niemi. "Recovery of Lotic Communities and Ecosystems from Disturbance—A Narrative Review of Case Studies." *Environmental Management* 14:5 (September–October 1990): 547–69.

Watershed and Floodplain Management

Burby, Raymond J., and Linda C. Dalton. "Plans Can Matter! The Role of Land Use Plans and State Planning Mandates in Limiting the Development of Hazardous Areas." *Public Administration Review* 54:3 (May–June 1994): 229–37.

Burby, Raymond J., and S. P. French. "Coping with Floods: The Land Use Management Paradox." *Journal of the American Planning Association* 47 (July 1981): 289–300.

Burby, Raymond J., and E. J. Kaiser. *An Assessment of Urban Floodplain Management in the United States*. Technical Report 1. Madison: Association of State Floodplain Managers, June 1987.

A Casebook in Managing Rivers for Multiple Uses. Washington, DC: National Park Service, Association of State Wetland Managers, and Association of State Floodplain Managers, 1991.

Corn, M. Lynne. "Ecosystems, Biomes and Watersheds: Definitions and Use." Congressional Research Service Report for Congress, July 14, 1993.

Federal Emergency Management Agency. *A Unified National Program for Floodplain Management*. US Government Printing Office, 1986.

Gruntfest, E., ed. *Multi-Objective River Corridor Planning*. Proceedings from workshops held March 14–16, 1989, at Colorado Springs, CO, and March 21–23, 1989, at Knoxville, TN. Berne, NY: Association of State Floodplain Managers, May 1991.

Heimlich, R. E., M. B. Carey, and R. J. Brazee. "Beyond Swampbuster: A Permanent Wetland Reserve." *Journal of Soil and Water Conservation* 44:5 (September–October 1989): 445–50.

Hoffman, Chuck. "Does Anybody Really Do Watershed Management?" *River Voices* (Summer 1994): 10–15.

Holway, James M., and Raymond J. Burby. "The Effects of Floodplain Development Controls on Residential Land Values." *Land Economics* 66:3 (August 1990): 259–71.

———. "Reducing Flood Losses: Local Planning and Land Use Controls." *Journal of the American Planning Association* 59:2 (Spring 1993): 205–16.

Kitch, Harry E. "Limiting the Impact of Future Floods." *USA Today* (July 1994): 36–39.

King, Dennis M., and Curtis C. Bohlen. "Compensation Ratios for Wetland Mitigation." University of Maryland, Center for Environmental and Estuarine Studies, April 1, 1994.

King, Dennis M., Curtis C. Bohlen, and Kenneth J. Adler. "Watershed Management and Wetland Mitigation: A Framework for Determining Compensation Ratios." University of Maryland, Center for Environmental and Estuarine Studies, 1993.

Kusler, Jon, and Larry Larson. "Beyond the Ark: A New Approach to U.S. Floodplain Management." *Environment* 35:5 (June 1993): 7–10, 31–34.

Larson, Larry A. "Tough Lessons from Recent Floods." *USA Today* (July 1994): 33–35.

McShane, John H. "Integrating Hazard Mitigation, Resource Protection, and Watershed Planning to Facilitate a Unified National Program for Floodplain Management." Unpublished paper, 1994.

Newson, Malcolm D. *Land, Water, and Development: River Basin Systems and Their Sustainable Management.* New York: John Wiley & Sons, 1992.

Omernik, James M., and Glenn E. Griffin. "Ecological Regions versus Hydrologic Units: Frameworks for Managing Water Quality." *Journal of Soil and Water Conservation* 46:5 (September–October 1992): 334–40.

Parks, Peter J., and Randall A. Kramer. "A Policy Simulation of the Wetlands Reserve Program." *Journal of Environmental Economics and Management* 28:1 (1994): draft manuscript.

Platt, Rutherford H. *Intergovernmental Management of Floodplains.* Boulder: University of Colorado, Institute of Behavioral Science, 1980.

———. "Metropolitan Flood Loss Reduction Through Regional Special Districts." *Journal of the American Planning Association* 52:4 (Autumn 1986): 467–79.

River Federation: The National Association for State and Local River Conservation Programs. *Institutional Frameworks for Watershed Management Programs.* Washington, DC: US Environmental Protection Agency, 1994.

US Army Corps of Engineers, Water Resources Support Center, Institute for Water Resources. *National Wetland Mitigation Banking Study. Expanding Opportunities for Successful Wetland Mitigation: The Private Credit Market Alternative.* Alexandria, January 1994.

US Department of Agriculture, Soil Conservation Service. *The Watershed Approach to Nonpoint Source Pollution Prevention and Control.* Washington, DC, February 1994.

US Department of the Interior, National Park Service. *A Casebook in Managing Rivers for Multiple Uses.* Washington, DC, October 1991.

US Environmental Protection Agency. *The Watershed Protection Approach: An Overview.* Washington, DC, December 1991.

US Water Resources Council. *State and Local Acquisition of Floodplains and Wetlands.* Prepared by Ralph M. Field Associates, Inc., 1981.

White, Gilbert. *Action Agenda for Managing the Nation's Floodplains.* Special Publication 25. Boulder: Natural Hazards Research and Applications Information Center, 1992.

Williams, Philip B. "Flood Control vs. Flood Management." *Civil Engineering* (May 1994): 51–54.

Young, C. E., and C. T. Osborn. *The Conservation Reserve Program: An Economic Assessment.* Agricultural Economic Report 626. US Department of Agriculture, Economic Research Service, February 1990.

Landscape Ecology, Ecosystem Management, and Landscape Restoration

Askins, Robert A., Margarett J. Philbrick, and David S. Sugeno. "Relationship Between the Regional Abundance of Forest and the Composition of Forest Bird Communities." *Biological Conservation* 39 (1987): 129–52.

Baird, K. "High Quality Restoration of Riparian Ecosystems." *Restoration and Management Notes* 7 (1989): 60–4.

Barton, D. R., W. D. Taylor, and R. M. Biette. "Dimensions of Riparian Buffer Strips Required to Maintain Trout Habitat in Southern Ontario Streams." *North American Journal of Fisheries Management* 5 (1985): 364–78.

Baumgartner, A. "Energetic Bases for Differential Vapourization from Forest and Agricultural Lands." In W. E. Sopper and H. W. Lull, eds., *Forest Hydrology*. Oxford: Pergamon Press, 1967, 381–89.

Bennett, Andrew F. "Habitat Corridors and the Conservation of Small Mammals in a Fragmented Forest Environment." *Landscape Ecology* 4:2/3 (1990): 109–22.

Berger, John, ed. *Environmental Restoration: Science and Strategies for Restoring the Earth*. Covelo, CA: Island Press, 1990.

Binford, Michael W., and Michael J. Buchenau. "Riparian Greenways and Water Resources." In Daniel S. Smith and Paul Cawood Hellmund, eds., *Ecology of Greenways: Design and Function of Linear Conservation Areas*. Minneapolis: University of Minnesota Press, 1993.

Blake, John G., and James R. Karr. "Breeding Birds of Isolated Woodlots: Area and Habitat Relationships." *Ecology* 68:6 (1987): 1724–34.

Cooper, J. R., J. W. Gilliam, R. B. Daniels, and W. P. Robarge. "Riparian Areas as Filters for Agricultural Sediment." *Soil Society of America Journal* 51 (1987): 416–20.

Deffontaines, J. P., C. Thenail, and J. Baudry. "Agricultural Systems and Landscape Patterns: How Can We Build a Relationship?" *Landscape and Urban Planning* 31 (1995): 3–10.

Forman, Richard T. T., and Michel Godron. *Landscape Ecology*. New York: John Wiley & Sons, 1986.

Forman, Richard T. T., Anne E. Galli, and Charles F. Leck. "Forest Size and Avian Diversity in New Jersey Woodlots with Some Land Use Implications." *Oecologia* 26 (1976): 1–8.

Fremark, Kathryn. "Assessing Effects of Agriculture on Terrestrial Wildlife: Developing a Hierarchical Approach for the US EPA." *Landscape and Urban Planning* 31 (1995): 99–115.

———, and H. G. Merriam. "Importance of Area and Habitat Heterogeneity to Bird Assemblages in Temperate Forest Fragments." *Biological Conservation* 36 (1986): 115–41.

Golley, Frank Benjamin. *A History of the Ecosystem Concept in Ecology.* New Haven: Yale University Press, 1993.

Gorman, Owen T., and James R. Karr. "Habitat Structure and Stream Fish Communities." *Ecology* 59:3 (1978): 507–15.

Gosselink, James. G., Suzanne E. Bayley, William H. Conner, and R. Eugene Turner. "Ecological Factors in the Determination of Riparian Wetland Boundaries." In J. R. Clark and J. Benforado, eds., *Wetlands of Bottomland Hardwood Forests.* Proceedings of a Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern United States, Lake Lanier, Georgia, June 1–5, 1980. New York: Elsevier Scientific Publishing Company, 1981.

Gosselink, James G., Gary P. Shaffer, Lyndon C. Lee, et al. "Landscape Conservation in a Forested Wetland Watershed. Can We Manage Cumulative Impacts?" *BioScience* 40:8 (September 1990): 588–600.

Grumbine, R. Edward. "What Is Ecosystem Management?" *Conservation Biology* 8:1 (March 1994): 27–38.

Henein, Kringen, and Gray Merriam. "The Elements of Connectivity Where Corridor Quality Is Variable." *Landscape Ecology* 4:2–3 (1990): 157–70.

Hersperger, Anna M. "Landscape Ecology and Its Potential Application to Planning." *Journal of Planning Literature* 9:1 (August 1994): 14–29.

Keiter, Robert B. "Beyond the Boundary Line: Constructing a Law of Ecosystem Management." *University of Colorado Law Review* 65:2 (1994): 293–333.

Kelly, John R., and Mark. A. Harwell. "Indicators of Ecosystem Recovery." *Environmental Management* 14:5 (September–October 1990): 527–45.

King, Dennis M. "Costing Out Restoration." *Restoration & Management Notes* 9:1 (Summer 1991): 15–21.

Lowrance, Richard, Sherwood McIntyre, and Clarence Lance. "Erosion and Deposition in a Field/Forest System Estimated Using Cesium-137 Activity." *Journal of Soil and Water Conservation* 43:2 (March–April 1988): 195–99.

Lowrance, Richard, Robert Todd, et al. "Riparian Forests as Nutrient Filters in Agricultural Watersheds." *BioScience* 34:6 (June 1984): 374–77.

Noss, Reed F. "A Regional Landscape Approach to Maintain Diversity." *BioScience* 33:11 (December 1983): 700–6.

———. "Corridors in Real Landscapes: A Reply to Simberloff and Cox." *Conservation Biology* 1:2 (August 1987): 159–64.

———, and Larry D. Harris. "Nodes, Networks, and MUMs: Preserving Diversity at All Scales." *Environmental Management* 10:3 (May 1986): 299–309.

Omernik, James M. "Ecoregions: A Spatial Framework for Environmental Management." Corvallis, OR: US Environmental Protection Agency, Environment Research Laboratory, 1994 (draft).

———. "Ecoregions of the Coterminous United States." *Annals of the Association of American Geographers* 77:1 (1987): 188–225.

———, A. R. Abernathy, and L. M. Male. "Stream Nutrient Levels and Proximity of Agricultural and Forest Land to Streams: Some Relationships." *Journal of Soil and Water Conservation* 36:4 (July–August 1981): 227–31.

Peterjohn, William T., and David L. Correll. "Nutrient Dynamics in an Agricultural Watershed: Observations on the Role of a Riparian Forest." *Ecology* 65:5 (October 1984): 1466–75.

Primack, Richard B. *Essentials of Conservation Biology*. Sunderland, MA: Sinauer Associates Inc., 1993.

Schonewald-Cox, Christine M., and Johnathan W. Bayless. "The Boundary Model: A Geographical Analysis of Design and Conservation of Nature Reserves." *Biological Conservation* 38 (1986): 305–22.

Simberloff, Daniel, and James Cox. "Consequences and Costs of Conservation Corridors." *Conservation Biology* 1:1 (May 1987): 63–71.

Simberloff, Daniel, and Nicholas Gotelli. "Effects of Insularisation on Plant Species Richness in the Prarie-Forest Ecotone." *Biological Conservation* 29 (1984): 27–46.

Society of American Foresters. *Ecosystem Management: Will It Work?* Special issue of *Journal of Forestry* 92:8 (August 1994).

Soulé, Michael E. "What Do Genetics and Ecology Tell Us About the Design of Nature Reserves?" *Biological Conservation* 35 (1986): 19–40.

Sparks, Richard E. "Need for Ecosystem Management of Large Rivers and Their Floodplains." *BioScience* 45:3 (March 1995): 169–82.

Thorne, James F., and Chang-Shan Huang. "Toward a Landscape Ecological Aesthetic: Methodologies for Designers and Planners." *Landscape and Urban Planning* 21 (1991): 61–79.

Vought, Lena B.-M., Gilles Pinay, Ann Fuglsang, and Charles Ruffinoni. "Structure and Function of Buffer Strips from a Water Quality Perspective in Agricultural Landscapes." *Landscape and Urban Planning* 31 (1995): 323–31.

Wegner, John F., and Gray Merriam. "Movement by Birds and Small Mammals Between a Wood and Adjoining Farmland Habitats." *Journal of Applied Ecology* 16:2 (1979): 349–58.

Wood, Christopher A. "Ecosystem Management: Achieving the New Land Ethic." *Renewable Resources Journal* 12:1 (Spring 1994): 6–12.

Woodley, Stephen, et al. *Ecological Integrity and the Management of Ecosystems.* Delray, FL: St. Lucie Press, 1993.

Property Rights, Risk Assumption, and National Flood Insurance Program

Baram, Michael S., and J. Raymond Miyares. "Managing Flood Risk: Technical Uncertainty in the National Flood Insurance Program." *Columbia Journal of Environmental Law* 7:2 (Winter 1982): 129–64.

Bernstein, Leonard A., Philip H. Myers, and Daniel Steen. "Flood Insurance Reform Act Engulfs Mortgage Lenders." *The Banking Law Journal* 112:3 (March 1995): 238–45.

Bollens, Scott A., Edward J. Kaiser, and Raymond J. Burby. "Evaluating the Effects of Local Floodplain Management Policies on Property Owner Behavior." *Environmental Management* 12:3 (May 1988): 311–25.

Bromley, Daniel W. *Environment and Economy: Property Rights and Public Policy.* Cambridge: Basil Blackwell, Ltd., 1991; esp. Chapter 1, "Property, Rights, and Property Rights," pp. 1–13; Chapter 2, "Property Rights and Property Regimes in Natural Resource Policy," pp. 14–40; and Chaper 4, "Property Rights and Externalities," pp. 59–83.

Coase, Ronald. "The Problem of Social Cost." *Journal of Law and Economics* (October 1960).

Dales, J. H. "Land, Water, and Ownership." In *Economics of the Environment: Selected Readings.* Ed. Robert Dorfman and Nancy S. Dorfman. Second edition. New York: W. W. Norton & Company, Inc., 1977.

Ellickson, Robert C. "Property in Land." *The Yale Law Journal* 102:6 (April 1993): 1315–1400.

Griffith, Charles T. "The National Flood Insurance Program: Unattained Purposes, Liability in Contract, and Takings." *William and Mary Law Review* 35:2 (Winter 1994): 727–65.

Hardin, Garrett. "The Tragedy of the Commons." In *Managing the Commons.* Ed. Garrett Hardin and John Baden. San Francisco: W. H. Freeman and Co., 1968, pp. 16–30.

Herke, John. "Teething Pains at 25: Developing Meaningful Enforcement of the National Flood Insurance Program." *Tulane Environmental Law Journal* 7:1 (Winter 1993): 165–96.

Hunter, David B. "An Ecological Perspective on Property: A Call for Judicial Protection of the Public's Interest in Environmentally Critical Resources." *Harvard Environmental Law Review* 12:2 (1988): 311–83.

Libecap, Gary D. "Property Rights in Economic History: Implications for Research." *Explorations in Economic History* 23 (1986): 227–52.

Phillips, William H., and Deborah L. Shannon. "Congress Reforms Flood Insurance." *ABA Bank Compliance* 15:10 (October 1994): 40–42, 44.

Pontius, Frederick W. "Federal Laws Protecting Wetlands." *Journal AWWA* (November 1990): 12–16, 102.

Sands, Rod. "A Refresher on Federal Flood Hazard Insurance Requirements." *The Practical Real Estate Lawyer* 11:2 (March 1995): 85–93.

Seltzer, E. Manning, and Robert E. Steinberg. "Wetlands and Private Development." *Columbia Journal of Environmental Law* 12:2 (1987): 159–201.

Singer, Saul Jay. "Flooding the Fifth Amendment: The National Flood Insurance Program and the 'Takings' Clause." *Boston College Environmental Affairs Law Review* 17:2 (Winter 1990): 323–70.

Spann, Bryant J. "Going Down for the Third Time: Senator Kerry's Reform Bill Could Save the Drowning National Flood Insurance Program." *Georgia Law Review* 28:2 (Winter 1994): 593–632.

Thunberg, E., and L. Shabman. "Determinants of Landowner's Willingness to Pay for Flood Hazard Reduction." *Water Resources Bulletin* 27:4 (August 1991).

Wise, Charles E., and Kirk Emerson. "Regulatory Takings: The Emerging Doctrine and Its Implications for Public Administration." *Administration & Society* 26:3 (November 1994): 305–36.