CHAPTER 15

The Flood of 1993

Charles Theiling

Extreme flooding on the Upper Mississippi and Missouri Rivers during the summer of 1993 was an unprecedented event, one that caused significant human hardship, tremendous economic losses, and extensive property and crop damage. This natural disaster also awakened many policy makers to the hazards of allowing uncoordinated development in floodplain environments.

Despite the human hardship endured during and after the Flood of 1993, positive consequences are being seen. The flooding may have benefited fish and wildlife directly through extended flood duration and indirectly through increased awareness of the value of floodplain ecosystems. The flood required coordination of State, Federal, and other relief agencies working to protect people and property during the flood, assess impacts after the flood and, importantly, reassess policies related to floodplain management.

Several summary documents are reviewed here to provide an overview of the flood, its economic and ecological effect, and policy recommendations developed in response to the flood.

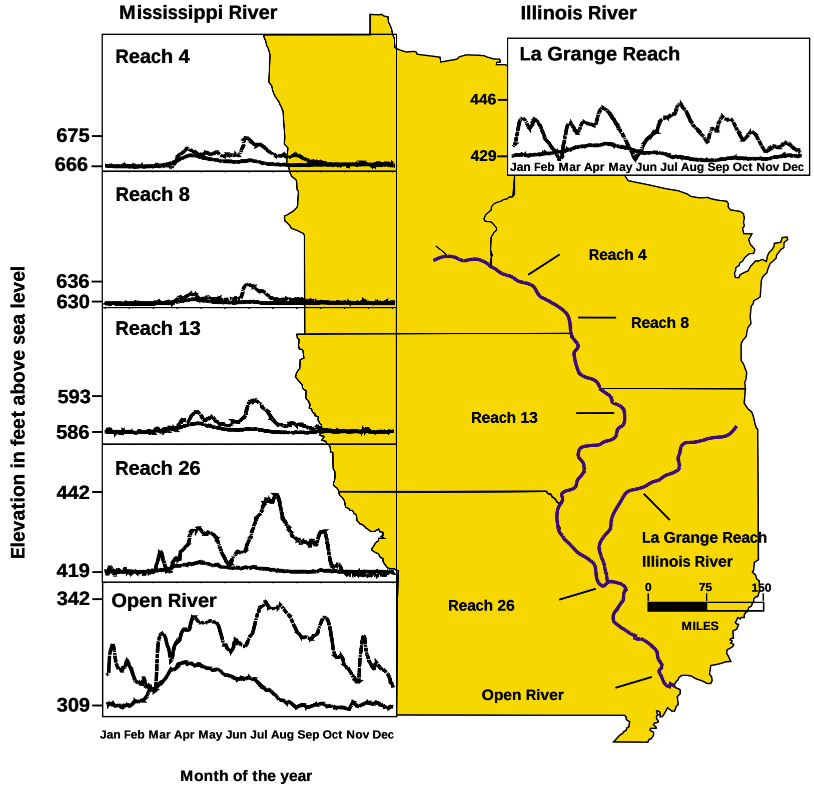
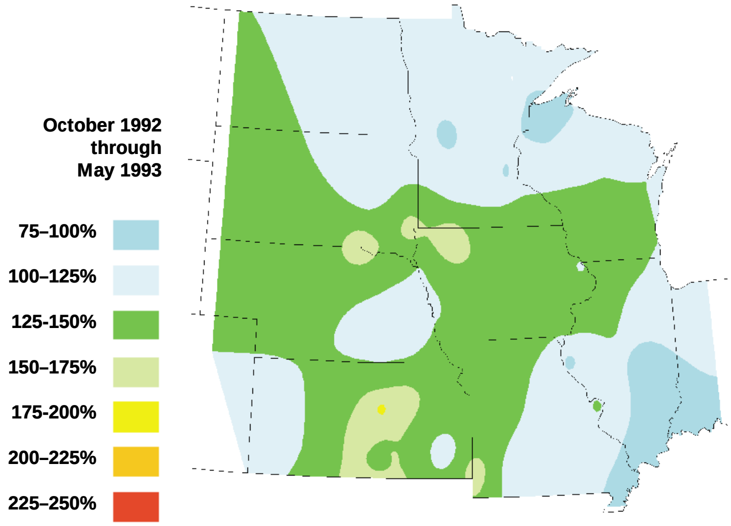


Figure 15-1.
Hydrographs from the six Long Term Resource Monitoring Program study reaches illustrate the divergence between the Flood of 1993 water levels (jagged upper line) and the 50-year postdam average (smooth lower line). The spring flood pulse shown in the postdam averages is increasingly overwhelmed in a downstream direction by the unusual summer flooding in 1993 (Source: Sparks 1996; John C. Nelson, Illinois Natural History Survey, Alton, Illinois).

Anatomy of the Flood

The extreme flooding of 1993 was the result of an unusually wet weather pattern stalled over the already-saturated Mississippi River Basin. During the fall of 1992, soil moisture values in the central United States were high. Additional rain and snow during the winter months added to the nearly saturated soils. Early spring rains and snowmelt further saturated most of the Midwest and Central Plains by March 1993; thus water from late spring and summer rains ran off to receiving streams and rivers (NOAA 1994; Rodenhuis 1996).

An evaluation of rain events responsible for the flood reveals five stages: (1) buildup phase (April and May), (2) transition phase (June), (3) sustained precipitation (July), (4) extended phase (August), and (5) intermittent events (September) (Rodenhuis 1996). Spring rains caused some flooding during April and May but the river receded during the latter part of May and early June (Figure 15-1). The more significant rains started mid-June and continued through most of July, with smaller rain events sustaining flood conditions during August. A few isolated September storms raised river levels again



June 1993
through
September 1993

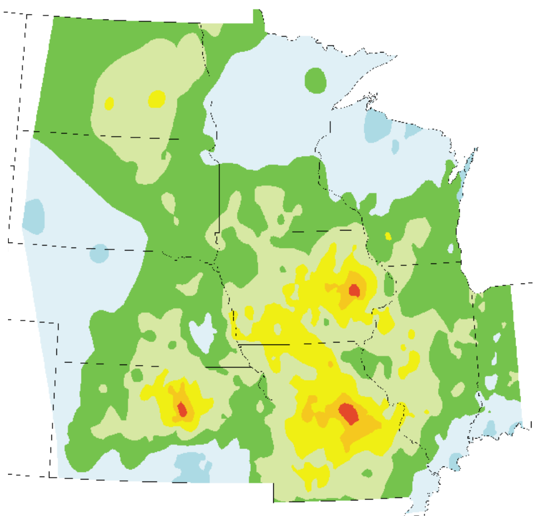


Figure 15-2. **Distribution of rainfall for periods before and during the summer of 1993. The weather pattern, stalled over the west central part of the Upper Mississippi River Basin, produced 1.5- to 2-times the normal amount of rain (Source: Inter-agency Floodplain Management Review Committee 1994).**

(Figure 15-1). An assessment of rainfall distribution is summarized in Figure 15-2. Most areas received higher than normal rain between October 1992 and May 1993. But between June and September 1993 rainfall exceeded 150 percent of normal throughout much of the basin (IFMRC 1994).

The most unusual rains, those that occurred during June and July, were the result of the convergence of cool dry air from the northwest and warm moist air from the south (Figure 15-3; NOAA 1994, Rodenhuis 1996). Rainfall throughout the Mississippi and Missouri Basins caused record flooding, estimated to be a 500-year event in the lower half of the Upper Mississippi River (Figures 15-4, 15-5 and 15-6 [see page 4]). The maximum discharge at the St. Louis gauge was 1,070,000 cubic feet per second (cfs; 30,300 cms) at a stage of 49.58 feet (15.1 m), almost 6.3 feet (2 m) higher than the previous record (Koellner 1996). Over 20 million acres (8.1 million ha) were affected by the flooding (Wright 1996).

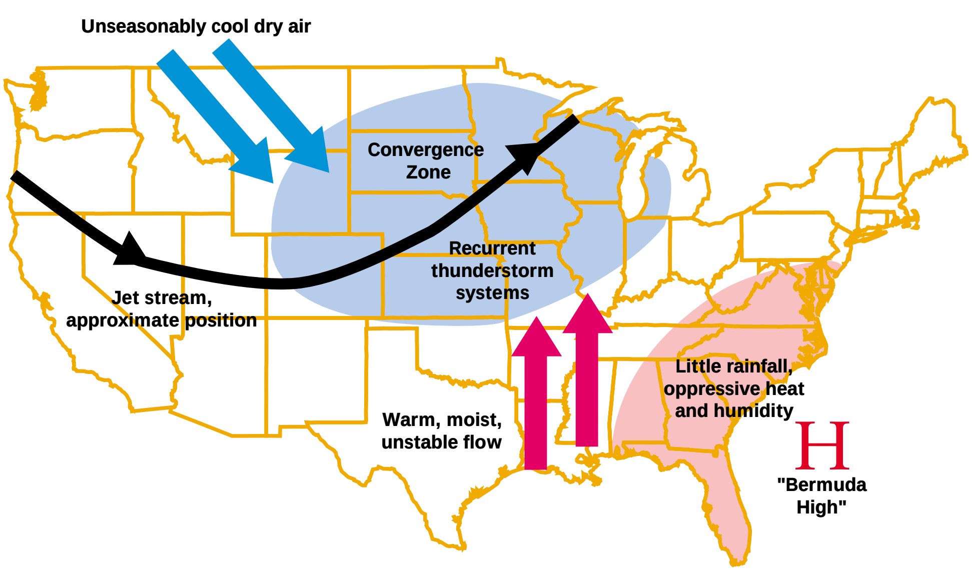


Figure 15-3. **This weather map illustrates how cool dry air from the northwest converged with warm moist air from the south to produce the unusually heavy and steady rains that occurred during June and July of 1993 (Source: National Oceanic and Atmospheric Administration 1994).**

Consequences of the Flood

The consequences of the flood will be discussed in relation to (1) the human perspective—focusing on the economics of property damage, crop loss, and disrupted transportation—and (2) the ecological perspective—examining both positive and negative effects on the physical environment and a variety of floodplain flora and fauna.

Figure 15-4. **Flooding was evident throughout the entire Upper Mississippi River System Basin, and in many places new record river stages were set (Source: SAST 1996).**

The Human Perspective

Safety and Shelter

As a human catastrophe, the flood affected parts of nine Midwest states, causing 52 deaths, leaving 74,000 people homeless, disrupting 30,000 jobs and day-to-day life for 149,000 households (Wilkins 1996;

Figure 15-5. **An aerial view (left) looking upstream from the confluence of the Mississippi and Missouri Rivers provides a striking example of the extent of the 1993 flooding (Source: Surdex, Inc., St. Louis, Missouri).**

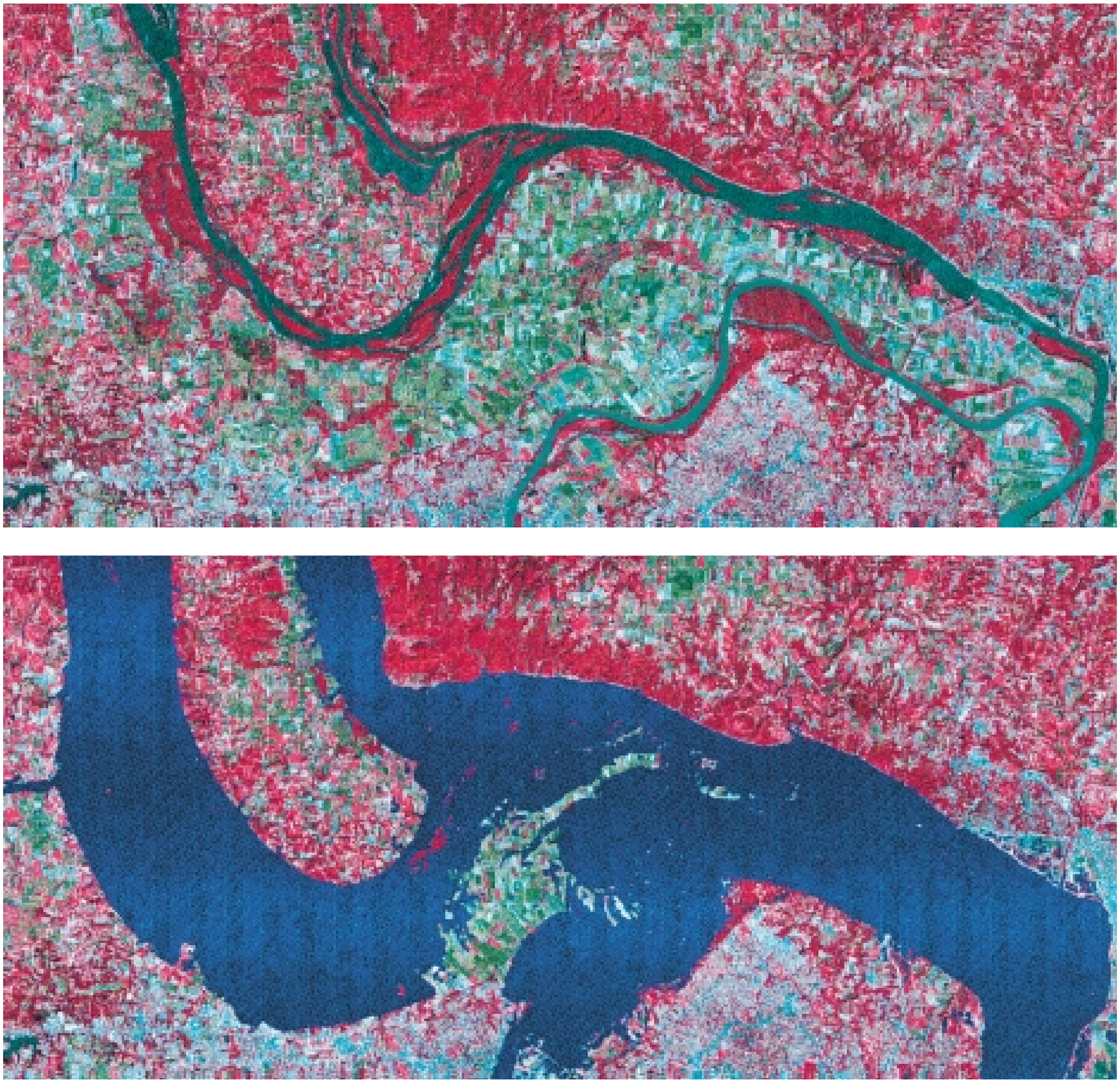


Figure15-6. **The same approximate area as seen in Figure 15-5 shows the view from space of the convergence of three large rivers. Satellite images during low water (top) and flood stage (below) provided data necessary to quantify the flood and evaluate its impacts (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin, and SAST 1994)**

Wright 1996). The Red Cross responded rapidly, providing emergency shelter for 14,500 people and serving 2.5 million meals at a cost of $30 million (Wilkins 1996). National Guard and Coast Guard personnel were dispatched to flood-affected regions to provide rescue and security services. As identified by the U.S. Environmental Protection Agency, 200 water treatment plants, including those serving sizable communities such as Des Moines, Iowa; Alton, Illinois; and St. Joseph, Missouri, were affected by the flooding. Consequently, hundreds of thousands of people were forced to boil water or get it from distribution stations. Damages to water control facilities exceeded $20 million (Wilkins 1996).

Beyond basic facts, the 2-month disruption of daily routine—including the search for shelter and food and the challenge of meeting short- and long-term needs of reconstruction or relocation—put a strain on families and did considerable psychological damage. Some among the dislocated population manifested the damage in increased alcohol and drug use, domestic abuse, and other stress-related behaviors (Wilkins 1996). Even after the flood, environmental factors (including floods) remained high on the list of concerns for people in Missouri (Wilkins 1996).

On a positive note, the flood contributed to a stronger sense of community. For example, in some areas nearly 50 percent of the sandbaggers and relief volunteers—almost half the population of Missouri—came from unaffected areas, across both the state and the country, to help their neighbors in the floodplain (Wilkins 1996).

Property Damage and Recovery

Property damage was widespread throughout the basin and not limited to the floodplain regions. Total property damage was estimated at $12 billion, of which $6.2 billion was reimbursed by the U.S. Congress. Additionally, the Federal Emergency Management Agency provided $650 million in public assistance and Small Business Administration loans exceeded $334 million. The loss of private residences was estimated at 70,500 homes, with as many as 149,000 homes damaged (Wilkins 1996). Over 1,900 businesses closed and 5,000 were affected during the flood (IFMRC 1994). Floodplain agriculture (Figure 15-7), commercial navigation, and riverfront industry were virtually shut down by the flooding (Chagnon 1996b). Damages sustained outside the floodplain area included basement flooding in Chicago, Illinois, aquifer emergence in central Illinois (Bhowmik et al. 1994), and saturated upland crop fields.

Figure 15-7. **Farms in the Upper Mississippi River System (UMRS) floodplain suffered extensive flooding during the growing season of 1993. A major land use in the UMRS, agriculture was one of the industries hardest hit by the Flood of 1993. Recovery was rapid, however, and most areas were planted and harvested the following year (Source: *St. Louis Post-Dispatch*).**

Crop Damage and Loss

Crop damage was widespread, with more than 70 percent of crop losses resulting from wet conditions that prevented planting or harvesting in the uplands (Zacharius 1996). In all, 12.7 million acres (5.1 million ha) of corn and soybeans, representing 8 percent of the total for nine midwestern states, were not harvested. This meant $2.85 billion in flood disaster payments from the U.S. Department of Agriculture (IFMRC 1994).

Whereas the immediate loss of crop production, equipment, and buildings was serious, many floodplain farmers on the Missouri and Middle Mississippi Rivers found their fields ruined—scoured or filled with sediment and sand. In Missouri alone, 455,000 acres (184,139 ha), about 60 percent of the floodplain cropland, were damaged. This included 77,500 acres (184,100 ha) covered with up to 2 feet (0.6 m) of sand and 59,000 acres (23,877 ha) covered

Figure 15-8.
Inundated households and farms were a source of a wide variety of chemicals found in kitchens, garages, and barns. Because they are isolated, floodplains often are used for illegal dumping and are an additional source of chemical contaminants. In this photo, hazardous waste clean-up crews were in the process of collecting, sorting, and disposing of contaminants swept up in the flood.

with *more* than 2 feet (Wilkins 1996). In areas where soil fertility was restorable, costs were $190 per acre ($77 per hectare), compared to $3,200 per acre ($1,300 per hectare) if sand had to be removed (i.e., where sand was more than 2 feet [0.6 m] deep; IFMRC 1994). Despite the extensive damage, only 27,000 flood-affected acres (10,926 ha) in Missouri remained unplanted in 1994 (Wright 1996).

Transportation: Commercial and Commuter

Transportation systems sustained almost $2 billion in damages and lost revenues throughout the basin. The effect was great because railroads, highways, and airports commonly are built on flat floodplain terrain close to large urban areas. Commercial barge traffic was closed for more than one month, but delays and congestion disrupted barge-company business until November 1993 as stranded barges continued their interrupted journeys to Southern ports. Total cost to the barge industry includes $600 million in direct costs and $320 million in losses to affected businesses.

Railroads experienced $241 million in damages and rerouting costs, a loss of $169 million in revenues. Over 800 miles (1,287 km) of track were damaged and many mainline tracks parallel to the rivers were inundated for months. Through cooperation and track sharing, several rail lines worked together to develop routes north and south of the flooded area, frequently using abandoned lines.

Inundated highways created significant problems for commuters in urban areas such as St. Louis and Kansas City, Missouri, and Quincy, Illinois. Flooded bridge approaches at one time left only one bridge open between St. Louis, Missouri, and Davenport, Iowa, a distance of 250 miles (402 km). Damage to highways totaled $434 million with an additional $150 million attributed to lost revenues. In addition, 33 airports experienced $5 million in flood damage, with the Spirit of St. Louis Airport accounting for $1.2 million of the total (Summarized from Chagnon 1996a and IFMRC 1994).

Ecological Perspective

The Flood of 1993 had both positive and negative effects on the ecology. Negative effects include water-quality degradation by massive inputs of agricultural chemicals, sewage, livestock waste, and industrial and household chemicals; high tree mortality in floodplain forests; the drowning of small, relatively immobile mammals, reptiles, and amphibians as levees were breached and levee districts flooded overnight; and the loss of wetland plant production to support migratory waterfowl.

On the positive side, an extended flood pulse during the warm summer months proved beneficial to fishes. As flood waters encroached onto unleveed floodplains, aquatic insects flourished on decaying herbaceous plants. Fish populations congregated to feed on the abundant food resources and spawn in the expanded habitat. Having the Long Term Resource Monitoring Program (LTRMP) field stations located in and around the floodplain area allowed immediate and continuing examination of flood ecology along the length of the Upper Mississippi River System (UMRS).

Water Quality and Chemical Input

Water quality was examined by the U.S. Geological Survey (USGS) for agricultural chemical input and by the LTRMP for other factors of ecological importance. Additional factors affecting water quality recorded as anecdotal information include hazardous household and industrial waste inputs (Figure 15-8), sewage plant and stockyard inundations, and superfund site floodings.

The USGS assessment of agricultural

chemical transport showed that the concentration of several common herbicides, such as atrazine, alachlor, cyanazine, and metachlor were similar to maximum concentrations recorded in other years (Goolsby et al. 1993). Similarly, nitrogen concentrations were equal to maximum concentrations measured in 1991 and 1992. Concentrations of these chemicals remained comparable to previous values; this is of concern because no dilution effect was exhibited. The ultimate quantity of several agricultural chemicals delivered to the Gulf of Mexico increased between 37 and 235 percent from previous estimates (Figure 15-9; Goolsby et al. 1993). Sparks (1996) emphasizes adverse effects in the Gulf of Mexico attributable to the flood. High nitrogen loading stimulated a plankton bloom which contributed to the development of a 7,000-square-mile (18,129 km^2) dead zone when it decayed. Importantly, none of the chemicals examined exceeded drinking water standards except for a few USGS samples.

The LTRMP assessment of water quality focused on such factors as dissolved oxygen, water clarity, current velocity, nutrient availability, and chlorophyll abundance. Most sampling was conducted to examine spatial differences between channel and floodplain habitats. In general, dissolved oxygen was lower throughout the UMRS with distinctions apparent depending on the location in the river-floodplain and the type of plants inundated. In the upper river reaches (Pools 8 and 13), turbidity was higher and apparently affected by proximity to tributary streams (Gent et al. 1994; Fischer and Dukerschein 1994). In more southern reaches, water clarity was higher in floodplain habitats than in channel habitats (Ratcliff and Theiling 1994). In Pool 26, Ratcliff and Theiling (1994) investigated floodplain water quality and found that several water constituents (conductivity,

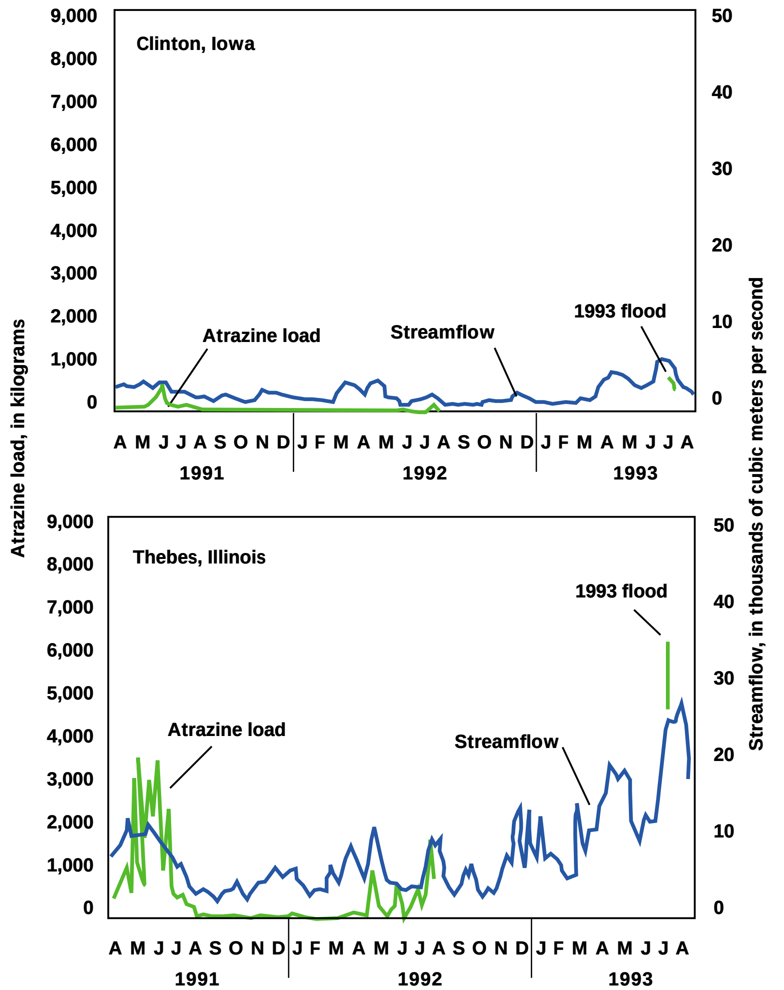


Figure15-9. **Atrazine is a herbicide used throughout the Upper Mississippi River Basin to control weeds in row crop agriculture. Its occurrence in Mississippi River water was tracked by the U.S. Geological Survey (USGS) in 1991 and 1992 and again in 1993 in response to the flood. Results show that compared to flows in 1991 and 1992, the load (i.e., the total amount transported to the river) was higher in 1993 than in previous years. The effects were evident especially where the flood was the greatest (Thebes, Illinois). The timing of the flood coincided with the application of atrazine (Source: Don Goolsby, USGS-Water Resources Division, Denver, Colorado).**

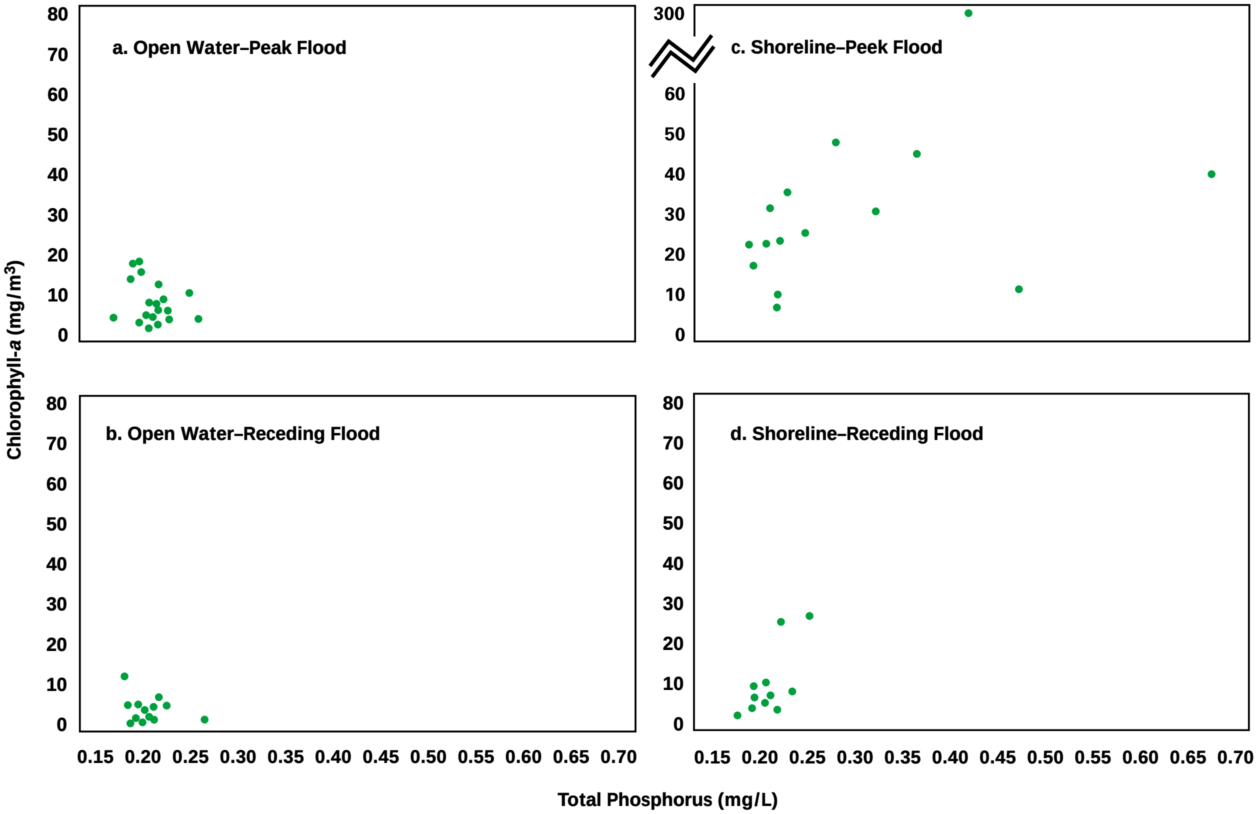


Figure 15-10. **The relation between nutrients (total phosphorus) and algae (chlorophyll-*a*) in flood waters reveal a pattern among different sites and flood stages. High total phosphorus concentrations at shoreline sites at the flood peak were positively correlated with chlorophyll-*a* concentrations (c), whereas both remained low at open water sites (a and b) and at the shoreline as the flood receded (d). The observation that higher algal concentrations are associated with phosphorus released from the floodplain supports the theory that inundated floodplains enhance the productivity of the river ecosystem (Source: Ratcliff and Theiling 1994).**

Preflood patterns of deposition in deeper areas and scour in shallow areas were reversed after the flood.

nutrients, suspended solids, and chlorophyll-*a*) were diluted because they occurred in river backwaters in significantly smaller concentrations than in previous years. One discovery that supports an aspect of the flood-pulse theory was finding higher concentrations of phosphorus and chlorophyll-*a* at shoreline sites (Figure 15-10).

Sediment Redistribution

Rogala and Boma (1994) investigated sediment redistribution in backwaters in Pools 4, 8, and 13. They found that preflood patterns of deposition in deeper areas and scour in shallow areas were reversed after the flood. Shallow backwater areas and floodplains accumulated sediment during the flood and deeper backwater areas were scoured, indicating that the wind-wave-dominated sedimentation processes usually found in lakes shifted to riverine processes.

Summarizing U.S. Army Corps of Engineers (USACE) channel-profile data and USGS suspended-sediment transport data, Bhowmik (1996) reported increased sediment transport over 9 months in 1993. Sediments were contributed by significant field erosion—up to 20 tons per acre (18.1 metric tons) compared to an average of 5 tons per acre (5.4 metric tons) in Iowa—and stream-bank erosion. Sediment transport was 6.7 million tons (6.1 million metric tons) at Dubuque, Iowa—33.7 million tons (30.5 million metric tons) at Keokuk, Iowa, and 60 million metric tons (54 million metric tons) at St. Louis, Missouri, over a short 3-month period.

Analyses of changes in channel morphometry is not complete, but preliminary analyses indicate more deposition than erosion. In the USACE St. Paul District, most pools showed net deposition up to 9 feet (2.7 m) but some areas eroded by 5 feet (1.5 m) and tributaries eroded by 10 feet (3 m). The USACE Rock Island District showed deposition or no change at 85 percent of the channel transects monitored. In the Middle River Reach, selected transects showed more sedimentation than erosion, with 20 feet (6 m) of sediment deposited in St. Louis Harbor.

Analyses of sediment deposition on the entire floodplain have not been completed, but more than 1,082 levees were overtopped and damaged, which allowed the river to drop sediments over hundreds of thousands of acres normally protected from flooding. The impact of levee breaks and breeches (Figure 15-11, following page) has been evaluated on the Missouri and Middle Mississippi Rivers where the effects were the most pronounced. One typical effect of a levee break includes development of a scour hole at the break with sediments spread in a fan-shaped area downstream from the break. Scour holes were variable in size and shape, but some were up to 100-feet deep (30 m) and 1-mile long (1.6 m). Sediment deposition (mostly sand) ranged from a few inches to up to 10 feet (3 m) and affected 455,000 acres (184,139 ha) in Missouri alone.

Channel Disruption

Two areas of “crossover flow,” where rivers can cut new channels, caused concern on the Mississippi River. Eighteen miles above the confluence with the Mississippi, the Missouri River flow split with about 50 percent traveling across St. Charles County to the Mississippi River. In the middle river reach near Miller City, Illinois, 20 percent of the river flowed through a levee break and 6 miles (9.7 km) over the floodplain to the downstream side of Dogtooth Bend. Both cutoff experiences raised concerns that the river would cut new channels and disrupt navigation (Summarized from Bhowmik 1996).

Aquatic Plants

The effect of flooding on submersed aquatic plants was much greater in the south where water levels were higher for longer periods. In Pool 8, many plants were scoured by swift waters whereas others responded by developing elongated stems to remain close to the surface where light was abundant. Most plant beds recovered after the flood though many areas experienced species changes (Langrehr and Dukerschein 1994). In Pool 13, the response was similar to that in Pool 8 except that plants were generally eradicated from areas where flood waters exceeded 13 feet (4 m; Gent and Blackburn 1994). In both locations the exotic plant Eurasian watermilfoil suffered large declines and was replaced by native species with higher wildlife food value. In Pool 26, the few backwater areas that typically support plants were inundated to depths greater than 20 feet (6 m) above normal and suffered near-complete submersed aquatic plant mortality (Redmond and Nelson 1994).

Wetlands and Floodplain Forests

The effect on wetland herbaceous plants was not studied in detail, although the trend probably follows that of submersed plants. In Pool 8, some emergent plants responded quickly after the flood, but increased flood duration further south limited the growth opportunity for emergent plants. Floodplain forests, conversely, were studied and the trend was again for a greater loss in southern regions. Yin et al.

More than 1,082 levees were overtopped and damaged, which allowed the river to drop sediments over hundreds of thousands of acres normally protected from flooding.

diversity (Sparks 1996). Yin et al. (1994) emphasize the importance of such disturbances in the development and maintenance of floodplain forests.

Macroinvertebrate Response

Aquatic-macroinvertebrate response to flooding was investigated in Pool 26 (Theiling et al. 1994) and results supported tenets of the flood-pulse concept. Generally macroinvertebrates were concentrated in shoreline habitats where they occurred in extremely high densities. The invertebrate community at the shoreline was dominated by detritivorous water boatmen on the rising flood but became more diverse as flood waters receded. The highest densities recorded were of flooded terrestrial herbaceous vegetation. Invertebrate density was lower in open water and channel habitats. Densities of all macroinvertebrates declined as the flood receded, perhaps because of the high rates of fish predation as invertebrates were forced from the refuge of flooded terrestrial vegetation.

Fish Survival and Growth

Investigations of fish response to the flood were conducted in Pools 8 and 26 and in the Unimpounded Reach. In Pool 8, Bartels and Dukerschein (1994) found catch rates lower than in previous years, which they attributed to the expanded aquatic area and reduced gear efficiency. They did note, however, the highest number of species in 4 years and the presence of two migratory species previously blocked by dams. In further investigations, Bartels (1995) demonstrated that bluegills showed better growth during the flood than in normal or drought years.

In Pool 26, Maher (1994) sampled 52 species on the inundated floodplain. Slackwater species, such as bluegill, crappie, gizzard shad, golden shiner, and largemouth bass, dominated the catch. Catch

Figure 15-11. **Levees were damaged in two ways: from being overtopped as shown here, or from seepage. In either case the levees usually were eroded by the force of the water through the restricted space. Large, deep holes were scoured in the Unimpounded Reach and the Missouri River (Source: *St. Louis Post-Dispatch*).**

(1994) noticed a large number of trees did not leaf out in the spring of 1994, indicating latent mortality from the flood. Their sampling indicated tree mortality ranging from 1 to 37 percent for trees and 2 to 80 percent for saplings. The mortality was most pronounced in Pools 22, 26, and the Unimpounded Reach where high flood stages persisted longer (see Figure 9-7). Mortality differed among species but analysis revealed that larger trees fared better.

Wheras high tree mortality seems undesirable, the loss of some old trees may provide opportunities for new tree growth, which may in turn help maintain high mast production or species rates were higher than during previous years. Young-of-the-year fish also dominated the catch and individual fish were healthy and seemed to be growing quickly. Maher suggested that determination of the factors that limit fish productivity in the UMRS could be tested by evaluating overwinter survival of the strong year class of fish. Follow-up sampling in 1994 revealed that the large year class of centrarchids had not overwintered but a strong year class of carp was detectable (Fred Cronin, Illinois Natural History Survey, Alton, personal communication). Theiling and Tucker (Illinois Natural History Survey, Alton, unpublished data) found that fish-species diversity was increased in an isolated restoration area after the flood, but 2 years later the area had reverted to its former low-diversity community of tolerant species.

In the Unimpounded Reach sampling revealed substantial increases in the abundance of black crappie, a species not normally found in abundance in the Middle Mississippi. Catch rates of up to 8,000 adult and young-of-the-year black crappie per net set were thought to be the result of an input of fish from flooded reservoirs upstream on the Missouri River. The high catch rate of young-of-the-year crappie indicates that the adults found suitable spawning habitat on the floodplain. However, the entire year class was absent by 1995. The fish community appeared to be partitioned with centrarchids, shad, and buffalo on the floodplain and catfish and sauger in the channel. Significant in the catch was the presence of young-of-the-year blue suckers, a threatened species in Missouri and candidate for listing on the Federal Register (Robert Hrabik, Missouri Department of Conservation, Cape Girardeau, personal communication).

Bird Nesting and Feeding Patterns

The effect of the flood on birds has not been thoroughly established, although regional differences appear to exist. Wet weather in the prairie pothole region provided resources for unusually high nesting success in waterfowl breeding grounds. By fall, however, waterfowl migrating down the Mississippi corridors had fewer food resources on their southern migration since high water levels during most of the growing season reduced plant production in river wetlands. Wading birds had the benefit of large numbers of fish trapped in floodplain pools but they had to travel greater distances to find water shallow enough to feed (Steve Havera, Illinois Natural History Survey, Alton, personal communication). Although the effect on other birds has not been examined, high tree mortality may create new nesting and feeding areas.

Small Animal Losses

Large mammals usually were able to escape from harm, though many were forced into urban areas. Relatively immobile small mammals, reptiles, and amphibians, however, were drowned as levee districts flooded. At one site in St. Charles County, Missouri, Theiling and Tucker (unpublished data) documented large numbers of rodents, frogs, and snakes being rafted downstream on floating prairie thatch after a levee district flooded to a depth of 10 feet (3 m) over night. These species had not recolonized the site 2 years after the flood compared to an unleveed site on the Illinois River, which was repopulated the following year. Snakes recaptured in the leveed area 1 year after the flood showed significant weight loss because they were deprived of their prey base, largely composed of frogs. Tucker (1994) also noted a high rate of snake migration from upland areas back to their former floodplain habitat.

Large mammals usually were able to escape from harm, though many were forced into urban areas. Relatively immobile small mammals, reptiles, and amphibians, however, were drowned as levee districts flooded.

Lessons Learned

Ecological responses investigated during the flood have added to our understanding of river-floodplain ecology, river geomorphology, and basin hydrology. Many ecological responses support aspects of the flood-pulse concept, but this one-time extreme event cannot adequately confirm the theory. Hydrologic and geomorphologic responses are consistent with the physics of flow through channels and floodplains. One lesson to consider strongly, however, is the development of rapid-response plans to gather data necessary to refine hydraulic models and confirm ecological theories.

Policy lessons are much more complicated to assess because of the wide range of local, State and Federal agencies responsible for floodplain management. The Flood of 1993 brought to light the myriad agencies, relief programs, and building codes that had developed in uncoordinated fashion over many decades. Calls for sounder policy development led to creation of the Interagency Floodplain Management Review Committee (IFMRC) in January 1994. The Committee was asked to evaluate flood impacts from economic, environmental, and social policy perspectives with the objective of developing unified goals to reduce future risk and share the burdens of response equitably (IFMRC 1994).

The Flood of 1993 brought to light the myriad agencies, relief programs, and building codes that had developed in uncoordinated fashion over many decades.

Initial policy changes were associated with changes in or development of disaster assistance programs that ultimately cost the Federal Government $6.2 billion. As the emergency stage of the flood passed, the IFMRC reviewed the facts related to the Flood of 1993 and proposed "a better way to manage floodplains. It begins by establishing that all levels of government, all businesses, and all citizens have a stake in properly managing the floodplain. All of those who support risky behavior, either directly or indirectly, must share in floodplain management and in the costs of reducing that risk." The Committee continued with a proposal to support "a floodplain management strategy of, sequentially, avoiding inappropriate use of the floodplain, minimizing vulnerability to damage through both structural and nonstructural means, and mitigating flood damages when they do occur." A final major recommendation was "to develop and fund a national Floodplain Management Program..." (IFMRC 1994).

Charles Theiling is an aquatic ecologist at the USGS Environmental Management Technical Center, Onalaska, Wisconsin.

Contributors

John Nelson
Illinois Natural History Survey
Alton, Illinois

Eric Ratcliff
Illinois Natural History Survey
Alton, Illinois

St. Louis Post-Dispatch
St. Louis, Missouri

Surdex, Inc.
St. Louis, Missouri

References

Bartels, A. D. 1995. Growth of selected fishes in Navigation Pool 8 of the Upper Mississippi River: A test of the flood-pulse concept. M.S. thesis submitted to the faculty of the graduate school of the University of Wisconsin-La Crosse, December 1995. Reprinted by U.S. Geological Survey, Environmental Management Technical Center, Onalaska, Wisconsin, January 1997. LTRMP 97–R001. 63 pp. (NTIS #PB97–144117)

Bartels, A. D., and J. T. Dukerschein. 1994. A summary of fisheries changes observed in Pool 8 of the Upper Mississippi River System during and following the flood of 1993. Pages 117–125 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 190 pp.

Bhowmik, N. G. 1996. Physical effects: A landscape changed. Pages 101–131 *in* S. A. Chagnon, editor. The great flood of 1993: Causes, consequences, and impacts. Westview Press, Inc., Boulder, Colorado. 321 pp.

Bhowmik, N. G., A. G. Buck, S. A. Changnon, R. H. Dalton, A. Durgunoglu, M. Demissie, A. R. Juhl, H. V. Knapp, K. E. Kunkel, S. A. McConkey, R. W. Scott, K. P. Singh, T. D. Soong, R. E. Sparks, A. P. Visocky, D. R. Vonnahme, and W. M. Wendland. 1994. The 1993 flood on the Mississippi River in Illinois. Illinois State Water Survey, Champaign. Miscellaneous Publication 151. 149 pp.

Chagnon, S. A. 1996a. Impacts on transportation systems: Stalled barges, blocked railroads, and closed highways. Pages 183–204 *in* S. A. Chagnon, editor. The great flood of 1993: Causes, consequences, and impacts. Westview Press, Inc., Boulder, Colorado.

Chagnon, S. A. 1996b. Losers and winners: A summary of the flood's impacts. Pages 276–299 in S. A. Chagnon, editor. The great flood of 1993: causes, consequences, and impacts. Westview Press, Inc., Boulder, Colorado.

Fischer, J. R., and J. T. Dukerschein. 1994. A summary of water quality changes observed in Pool 8 of the Upper Mississippi River System during and following the flood of 1993. Pages 157–170 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 190 pp.

Gent, R., and T. Blackburn. 1994. Observations of aquatic macrophyte abundance in Mississippi River Pool 13 during the flood of 1993. Pages 3–15 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 191 pp.

Gent, R., D. Gould, and M. Hass. 1994. Observation of water quality at two backwater complexes in Upper Mississippi River System Pool 13 during the flood of 1993. Pages 139–156 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 190 pp.

Goolsby, D. A., W. A. Battaglin, and E. M. Thurman. 1993. Occurrence and transport of agricultural chemicals in the Mississippi River Basin. July through August 1993. U.S. Geological Survey Circular 1120-C. U.S. Geological Survey, Denver, Colorado. 22 pp.

IFMRC (Interagency Floodplain Management Review Committee). 1994. A Blueprint for change, Part V: Science for floodplain management into the 21st century. Report of the Floodplain Management Review Committee to the Administration Floodplain Management Task Force. U.S. Government Printing Office, Washington D.C. 191 pp. + appendices.

Koellner, W. H. 1996. The flood's hydrology. Pages 68–100 *in* S. A. Changnon, editor. The great flood of 1993: Causes, impacts, and responses. Westview Press, Boulder, Colorado.

Langrehr, H. A., and J. T. Dukerschein. 1994. A summary of changes observed in Pool 8 of the Upper Mississippi River during and following the flood of 1993. Pages 31–38 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011.

Maher, R. J. 1994. Observations of fish community structure and reproductive success in flooded terrestrial areas during an extreme flood on the Lower Illinois River. Pages 95–115 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 190 pp.

NOAA (National Oceanic and Atmospheric Administration). 1994. National disaster survey report: The great flood of 1993. U.S. Department of Commerce, Washington, D.C.

Ratcliff, E. R., and C. H. Theiling. 1994. Water quality characteristics during and prior to an extreme flood on the Lower Illinois River. Pages 171–190 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 190 pp.

Redmond, A. S., and J. C. Nelson. 1994. Observations of submersed aquatic vegetation in three backwater lakes of the Lower Illinois River before and after the 1993 flood. Pages 17–29 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 191 pp.

Rodenhuis, S. A. 1996. The weather that led to the flood. Pages 3–28 *in* S. A. Chagnon, editor. The great flood of 1993: Causes, consequences, and impacts. Westview Press, Inc., Boulder, Colorado.

Rogala, J. T., and P. J. Boma. 1994. Observations of sedimentation along selected transects in Pools 4, 8, and 13 of the Mississippi river during the 1993 flood. Pages 129–138 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 190 pp.

SAST (Scientific Assessment and Strategy Team). 1996. Science for Floodplain Management into the Twenty-First Century, Volume 3, Overview of river floodplain ecology in the Upper Mississippi River Basin. Volume edited by David L. Galat and Ann G. Frazier. Report edited by John A. Kelmelis. Scientific Assessment and Strategy Team Interagency Floodplain Management Review Committee, Washington, D.C. 149 pp.

Sparks, R. E. 1996. Ecosystem effects: Positive and negative outcomes. Pages 132–162 *in* S. A. Chagnon, editor. The great flood of 1993: Causes, consequences, and impacts. Westview Press, Inc., Boulder, Colorado. 321 pp.

Theiling, C. H., J. K. Tucker, and P. A. Gannon. 1994. Nektonic invertebrate distribution and abundance during prolonged summer flooding on the Lower Illinois River. Pages 63-81 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 190 pp.

Tucker, J. K. 1994. Notes on road-killed snakes and correlations with habitat modification due to summer flooding on the Mississippi River in West Central Illinois. Pages 83–94 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological

Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 190 pp.

Wilkins, L. 1996. Living with the flood: Human and governmental responses to real and symbolic risk. Pages 218–244 *in* S. A. Chagnon, editor. The great flood of 1993: Causes, consequences, and impacts. Westview Press, Inc., Boulder, Colorado. 321 pp.

Wright, J. M. 1996. Effects of the flood on national policy: Some achievements, major challenges remain. Pages 245–275 *in* S. A. Chagnon, editor. The great flood of 1993: Causes, consequences, and impacts. Westview Press, Inc., Boulder, Colorado.

Yin, Y., J. C. Nelson, G. V. Swenson, H. A. Langrehr, and T. A. Blackburn. 1994. Tree mortality in the Upper Mississippi River floodplain following an extreme flood in 1993. Pages 39–60 *in* National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources. 1994. Long Term Resource Monitoring Program 1993 flood observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94–S011. 190 pp.

Zacharias, T. P. 1996. Impacts on agricultural production: Huge financial losses lead to new policies. Pages 163–182 *in* S. A. Chagnon, editor. The great flood of 1993: Causes, consequences, and impacts. Westview Press, Inc., Boulder, Colorado. 321 pp.