Long Term Resource Monitoring Program

Special Report
97-S005

A Natural Approach for Flood Damage Reduction and Environmental Enhancement

August 1997

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August 1997

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Suggested citation:

Hunt, C. E. 1997. A natural storage approach for flood damage reduction and environmental enhancement. U.S. Geological Survey, Environmental Management Technical Center, Onalaska, Wisconsin, August 1997. LTRMP 97-S005. 16 pp.

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Preface

The Long Term Resource Monitoring Program (LTRMP) was authorized under the Water Resources Development Act of 1986 (Public Law 99-662) as an element of the U.S. Army Corps of Engineers' Environmental Management Program. The LTRMP is being implemented by the Environmental Management Technical Center (EMTC), a U.S. Geological Survey science center, in cooperation with the five Upper Mississippi River System (UMRS) States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. The U.S. Army Corps of Engineers provides guidance and has overall Program responsibility. The mode of operation and respective roles of the agencies are outlined in a 1988 Memorandum of Agreement.

The UMRS encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. Congress has declared the UMRS to be both a nationally significant ecosystem and a nationally significant commercial navigation system. The mission of the LTRMP is to provide decision makers with information for maintaining the UMRS as a sustainable large river ecosystem given its multiple-use character. The long-term goals of the Program are to understand the system, determine resource trends and effects, develop management alternatives, manage information, and develop useful products.

The basic ideas of this report were presented at the 1994 international conference “Sustaining the Ecological Integrity of Large Floodplain Rivers: Application of Ecological Knowledge to River Management.” The conference, organized by the EMTC and partners, was held in support of Goal 1, *Develop a Better Understanding of the Ecology of the Upper Mississippi River System and its Resource Problems*, of the LTRMP Operating Plan (USFWS 1993). The EMTC encourages the distribution of ideas such as those presented in this report, and its publication is consistent with the mission of the LTRMP.

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Abstract

The frequency and severity of flooding in the Upper Mississippi River Basin is influenced by three major factors: the amount and timing of precipitation, the condition of the basin's stream channels and floodplains, and the timing and rate of storm water conveyance off the watershed, which is a function of soil condition, extent of impervious surface, vegetation density, and other factors. To the extent that changing precipitation patterns result from human-caused changes in the global climate, this factor can be addressed through international efforts to reduce emissions of greenhouse gases. Careful planning and design can provide some control over the condition of channels, floodplains, and watersheds. The primary strategy employed by the United States and other developed nations for reducing flood damages has been to maximize the conveyance of storm water downstream and structurally alter channels and construct levees to protect adjacent communities from floods. Since the land behind 100-year levees was protected from flood stages with an annual probability of occurrence less than or equal to 1%, development was frequently allowed to occur on lands that would otherwise be within the 100-year floodplain, with no additional requirements for flood insurance or flood protection. An emerging approach to flood damage reduction retains water on the upland landscape and focuses on allowing historical floodplains to again provide storage and conveyance benefits for reducing flood peaks. Floodplains under this approach are used for storing and conveying floodwaters, and also function as water filters and habitat for fish and wildlife. To the maximum extent possible, vulnerable structures are removed from the 100-year floodplain. This approach is referred to as the "natural storage" approach.

Introduction

Floods annually cause greater damages and result in more presidentially declared disasters than all other forms of natural hazards combined (L. R. Johnston and Associates 1992). Nationwide, annual flood damages have been steadily increasing over the past century, despite increases in flood control expenditures. For the five 10-year periods from 1936 to 1985, average annual Federal flood control expenditures increased by 103% after adjusting for inflation (Eiker 1986). Data collected by the National Weather Service shows an increase in average annual flood damages of 268% between 1916 and 1985 after adjusting for inflation. Per capita flood damages were 2.5 times as great from 1951 through 1985 as they were from 1916 through 1950 after adjusting for inflation (L. R. Johnston and Associates 1992).

A natural storage approach to reducing flood damages relies largely on the ability of the landscape to store and gradually release water and on additional flood storage and conveyance in the floodplain. This approach contrasts with the traditional rapid conveyance approach, which provides protection against floods by increasing the rate at which water moves off of the landscape, thus preventing the water from accumulating on protected areas. The rapid conveyance approach reduces the duration of a flood while increasing the peak (Leach and Magner 1992; Moore and Larson 1980). In some landscape types, such as the prairie pothole region of the Midwest, a natural storage approach to flood damage reduction has the potential of providing a wide range of public benefits while reducing many Federal costs. Careful targeting of incentive programs for wetland restoration and soil and water conservation can ensure an equitable balance of costs and benefits to the private sector, as well.

A natural storage approach can be preferable to a rapid conveyance approach for several reasons. First, structurally constrained high flood peaks present a greater risk to adjacent communities than do natural systems. These structures typically raise water levels by concentrating flows both spatially and temporally. Concentrated flows often increase pressure on a number of points in the water confinement system. The water pressure on the structures may increase until a breach in the system relieves the pressure by allowing the release of water onto the adjacent floodplain. The accidental breaching of a dam or levee can suddenly unleash a huge quantity of water in relatively unpredictable locations. Conversely, any lands inundated under a natural storage approach (assuming that most of the floodplain is available to store and convey flood water) are exposed to a smaller quantity of water at a more gradual rate, resulting in less damage.

Second, a rapid conveyance approach results in greater cumulative financial costs to society, including the publicly supported construction, maintenance, and repair of flood conveyance and control structures. The natural storage approach relies largely on relatively low-cost, low-maintenance soil conservation and wetland restoration projects, on mechanisms such as zoning regulations and floodplain insurance that carry only administrative costs or are largely self-financing, and on occasional relocations of structures that are frequently cost-effective compared with the cost of frequent repairs. Opportunity costs of these alternatives on agricultural land may be mitigated by increased productivity resulting from increased soil field capacity and soil organic matter content and decreased erosion (R. Seigel, Iowa Corn Growers Association, 1997, personal communication). On urban landscapes, opportunity costs can be mitigated by such market mechanisms as cluster developments and transferable development rights and through the increased land values that typically accompany homes and businesses in a natural setting.

Third, the natural storage approach provides a wide range of environmental benefits that are lacking under the rapid conveyance approach. These include natural reduced soil erosion, improved water quality, enhanced wildlife habitat, augmented groundwater recharge, and an increased diversity of recreational opportunities. In addition, the natural storage approach can reduce many public costs, such as the costs of dredging and spoil disposal on navigable waterways; the costs of federally subsidized crop insurance; the costs of constructing, operating, and maintaining structural flood control projects; and the costs associated with the long-term decline of agricultural land, wildlife habitat, and commercial and recreational fisheries.

The following discussion supports the use of a natural storage approach to reduce flood damages by restoring the river basin's natural hydrology. The Upper Mississippi River Basin (UMRB) is used as a model, although the management implications should apply elsewhere.

Increasing Flood Damages in the Upper Mississippi River Basin

A trend toward increased flood frequency is evident in the UMRB. Data analyzed by the Midwestern Climate Center of the Illinois State Water Survey (Chagnon and Kunkle 1995) showed an upward trend in the occurrence and intensity of floods from 1921 through 1985 across Minnesota, Iowa, and northern Illinois. Cold-season flooding also showed significant upward trends in northern Illinois, Minnesota, Iowa, and Missouri.

Flood severity on the Upper Mississippi River is also increasing. On the Mississippi River at St. Louis, the relation between Mississippi River stage and river flow was relatively stable and predictable from 1861 to 1927. The relation fluctuated increasingly after that, with low flows becoming lower and high flows becoming higher (Belt 1975). As a result, for any given volume of flood flow in the river, the flood stage is now higher than it was during 1861 to 1927.

Three factors contribute to the trend toward increased frequency and severity of flooding in the UMRB: increased precipitation, constriction of the river channel by levees and other floodplain structures, and changes in watershed management. The first of these factors, to the extent that it resuts from human-induced global climate change, can be addressed through reductions in greenhouse gas emissions over several decades. We can control the second and third factors more quickly by changing the way in which we manage channels, floodplains, and watersheds.

Increasing Precipitation

A large portion of the UMRB, including Iowa, northern Illinois, and parts of Wisconsin and Minnesota, has experienced increases in floods and heavy precipitation during the last half of the twentieth century. The Midwest Climate Center analysis indicated that preflood heavy precipitation in Minnesota, Iowa, and northern Illinois in warm seasons increased in frequency between 1921 and 1985. All areas where precipitation increased had notable increases in flooding. Patterns of trends in cold-season flooding and heavy precipitation also showed strong spatial agreement. The data suggest that flood trends, generally upward, were largely due to precipitation shifts (Chagnon and Kunkle 1995).

The record-breaking flood of 1993 in the UMRB was primarily caused by an abnormally heavy rain pattern. Record and near-record summer precipitation fell on soil saturated from previous seasonal precipitation and spring snowmelt, resulting in flooding along major rivers and their tributaries (USACE 1994). Rainfall totals for the UMRB were by far the largest of this century in summer 1993 (Kunkle et al. 1994). Precipitation over central Iowa during January through July 1993 was as much as 200% of the 30-year precipitation normal for those months from 1961 through 1990 (Parrett et al. 1993).

Structural Constriction of River Channels and Floodplains

A second factor in the increase in flood severity and in flood frequency in unprotected areas is the constriction of the floodplain and channels of the Upper Mississippi River and tributaries by levees and other structures. Historical and scientific literature reflects that these concerns are not new. The Illinois Department of Purchases and Construction stated in 1930 that the floods of 1844, 1904, 1913, 1926, and 1927 were reaching successively higher stages because of floodplain constriction by levees (Mulvihill and Cornish 1930). Belt (1975) compared the 1844 and 1973 Mississippi River floods and concluded that, in 1973, the river crested at St. Louis 60 cm (2 feet) above the 1844 level, despite the fact that the flow in the river was 35% less. He attributed the difference to the loss of about one-third of the original channel volume. The American Society of Civil Engineers supported the conclusion that levees contribute to the increase in Mississippi River flood stages (Stevens et al. 1975). According to R. E. Sparks (1993, unpublished testimony before the U.S. House of Representatives Subcommittee on Water Resources and the Environment, Washington, D.C.), although the 1993 flow was about 20% less than the 1844 flood, the 1993 crest was 20% higher.

The restoration of the natural functions of the floodplain has been suggested as a solution to reverse the increase in the frequency and severity of Mississippi River floods. Scientists reporting on Mississippi River floods in 1989 advocated the creation of a floodway, similar to the "flood retention spaces" that have been proposed for the Rhine River (Grubaugh and Anderson 1989). The National Research Council (NRC; 1992) has also recommended that Federal funds be diverted from Federal construction projects to aquatic ecosystem restoration projects.

National policy on the use of floodplains has already shifted in response to the 1993 floods. Increased Federal funding has been made available to relocate communities out of the floodplain. The Federal

Emergency Management Agency estimates that about 10,000 structures, representing roughly 20% of the total number of structures damaged by overland flooding, will be removed from the floodplain (K. Helbrecht, Federal Emergency Management Agency, Washington, D.C., 1995, unpublished data). The U.S. Department of Agriculture designated nearly $100 million of its emergency supplemental appropriations for wetland restoration and purchase of easements in flood-damaged agricultural lands.

Increased Rates of Conveyance From the Watershed

The increased frequencies and flood stages along the Upper Mississippi River and tributaries can also be attributed to alteration of the watershed. A landscape characterized by deeply rooted prairie grasses, stable soils rich in organic matter, and numerous wetlands providing temporary storage areas for storm water has been transformed. The modern watershed is an agricultural system characterized by annual vegetation; unstable, eroded soils; and drainage systems that move water rapidly into stream channels. As a result, water moving quickly over bare and compacted soils and through drainage ditches contributes to flood stages during storms, and less water is available to replenish the aquifers that maintain streamflow in dry seasons.

If flood peaks are to be reduced, the restoration of some of the historical characteristics of the watershed is necessary. Such an approach will require the restoration of wetlands and the installation of soil and water conservation practices, as well as the use of portions of the floodplain for flood water storage and to provide sufficient area to allow unimpeded, downstream conveyance.

The Benefits of a Natural Storage Approach

Postsettlement land use and subsequent hydrologic changes in the Upper Mississippi River have contributed to increased floods. Constructed and restored wetlands, installed and managed in conjunction with ecologically sound agricultural practices, are efficient at reducing downstream flood peaks and improving water quality (DeLaney 1995). These practices could provide significant additional environmental and economic benefits, making the benefits of such an effort well worth the costs (USACE 1995).

Wetland Drainage and Restoration

Before the UMRB was extensively settled by Europeans, it was characterized by extensive and variable wetlands. The hummocky land surface left by retreating glaciers markedly retarded runoff and enhanced the ponding of water (Winter 1992). Prairie ecosystems, dominated by perennial grasses, ranged from mesic to wetland communities in a gently rolling landscape where defined stream channels were rare and marshy swales conveyed water downstream. The UMRB, including the Missouri River Basin, contains more than 16 million ha (40 million acres) of hydric soils (Hey and Philippi 1995). These soils, which form under anaerobic (oxygen-deficient) conditions caused by prolonged and repeated saturation or inundation, indicate the likely historical extent of wetland systems in the basin.

Farmers were attracted to the rich prairie soils of the UMRB throughout the nineteenth century. To maximize productivity, however, it was necessary to drain water from low-lying areas. The Federal Government provided substantial assistance to farmers in accomplishing this task. The Swamp Land Act of 1849 was designed to decrease Federal involvement in flood control by turning wetlands over to states for "reclaiming" by drainage and levee districts. When the law was originally passed, it applied to Louisiana only, but was extended in 1850 to include, among other states, Illinois, Missouri, Wisconsin, and Iowa. Minnesota was added in 1860. By 1854, an estimated 26 million ha (65 million acres) of land were granted to 15 states for reclamation. Between 1940 and 1977, the U.S. Department of Agriculture's Agricultural Conservation Program led to the drainage of 23 million ha (57 million acres) of wetland nationally. Wetland drainage was also hastened by the Depression-era Works Progress Administration and Soil Conservation Service (SCS; Mitsch and Gosselink 1986). Many states organized to form drainage districts as well. By 1967, about 50 million ha (124 million acres) of land nationwide had been drained for agriculture, of which about 40 million ha were in drainage districts. Between the mid-1950s and mid-1970s, an average of more than 185,000 ha of wetland were lost each year in the conterminous United States, an annual loss roughly equal to half the size of Rhode Island. About 87% of this loss was the result of conversion to farmland (M. Reuss, Interagency Committee on Floodplain Management, Washington, D.C., 1994, unpublished paper).

While debate continues over the effects of artificial drainage on flood peaks, a majority of studies indicate that drainage improvements, in combination with a change in land use to agriculture, increase peak runoff rates, sediment losses, and nutrient losses (Skaggs et al. 1994). A study performed in North Carolina, for example, showed that an open-ditch drainage system plus land conversion from natural vegetation to corn, soybean, and pasture increased peak runoff rates at the field edge by a factor of 2 to 4 (Skaggs et al. 1980). Researchers in Iowa studied the hydrological effects of channelizing riparian lands and found substantial increases in peak discharges (Campbell et al. 1972). Engineers studying drainage in Jackson County, Minnesota, found that surface drainage of depressional areas significantly increased annual runoff, storm runoff volume, and peak discharge; they also found that, when soil moisture levels were high, significant increases in storm runoff volume and discharge occurred to subsurface drainage (Moore and Larson 1980). Conversely, results of models run on several upper Mississippi River subbasins (Scientific Assessment and Strategy Team 1994) indicate that wetland restoration could significantly reduce peak flood flows.

Other investigators have examined the potential for wetland restoration as part of a flood damage reduction strategy and have reached similar conclusions. The U.S. Fish and Wildlife Service (Arlington, Virginia, 1993, unpublished data) estimates that more than 8 million ha (19 million acres) of wetlands in the UMRB have been drained, and that these wetlands would provide nearly 30 million acre-feet of storage. Many hydrologists believe that most depressional storage in the watershed would have been filled early in the flood season and would therefore be unavailable to contain most flood flows. While the results of massive wetland restoration on the Mississippi mainstem during a flood of the magnitude experienced in 1993 are still being debated, the benefit of this approach for subbasins during more frequent events is widely acknowledged.

Wetlands can temporarily detain floodwaters and attenuate flood peaks. Watersheds with a large percentage of their area in wetlands generally have lower high-magnitude flows (Hollands et al. 1986). Wetlands can also desynchronize flood peaks. In a watershed that contains a variety of water retention systems, including wetlands and ponds and upland areas maintained in native vegetation types, the release of water to the watershed during heavy rainfall or snowmelt occurs at different rates from each area of retention. In contrast, a watershed designed to pass water quickly off the land and into a receiving stream will release most of the water virtually simultaneously, resulting in a larger flood peak or crest. Wetland losses can result in the loss of flood storage and can increase downstream flood profiles and downstream flooding (Larson 1987). Past research has shown mixed results regarding the effects of wetlands on flooding in specific regions (Demissie and Kahn 1993). Depending on the extent of the wetland, its geographic location, storm intensities and durations, and seasons of the year, the influence of wetlands on streamflow may vary greatly with the region as well as the specific wetland type.

In addition to the potential benefits of restored wetlands in reducing flood damages downstream, wetland restoration can reduce the demand for disaster and crop insurance payments on drained hydric soils after flooding. After the Mississippi River floods of 1993, 70% of U.S. Department of Agriculture disaster assistance payments and 80% of Federal crop insurance payments went to agricultural damages in upland areas where water ponding and soil saturation prevented either planting or harvesting of crops. Data compiled by government scientists show a high visual correlation between counties with the highest levels of flood-related crop losses, Federal crop insurance and disaster assistance payments, and the presence of drained hydric soils (Scientific Assessment and Strategy Team 1994). An evaluation of this data (Kelmelis et al. 1996) indicates that although the majority of crop insurance payments went to floodplain areas in these counties, the drained, upland areas that received the lion's share of disaster assistance were uninsured. Many millions of disaster dollars could be saved by the U.S. Government if all farmers were required to participate in the insurance program. Such a policy could also deter farmers from growing crops in flood-prone depressions.

Wetlands scattered throughout the landscape of the UMRB have the following advantages over dams for reducing flood damages. First, by providing storage throughout the watershed the risk of a storm system locating below a reservoir and flooding property left unprotected by a more concentrated storage system is greatly reduced. Second, wetlands, in the absence of major sources of sedimentation upstream, are essentially self-maintaining. Third, the use of wetlands rather than dams for retaining storm water eliminates the risk of dam failure and destruction of downstream communities. Fourth, water retained by wetlands during wet seasons can replenish groundwater supplies, ensuring a more uniform year-round flow volume in the receiving stream and reducing drought-related crop losses. Fifth, wetlands can supply benefits, such as water quality and biological diversity support, which dams generally do not (Collier et al. 1996).

Properly designed wetland restoration projects can decrease pollutant loads in surface water. Wetland vegetation removes pollutants, including biological oxygen demand, nitrogen, phosphorus, total suspended solids, coliform bacteria, and heavy metals, from wastewater (Hammer 1989). Wetlands can also remove pollutants from water through adsorption to or incorporation into sediments or biota and degradation and export them to other ecosystems. Mechanisms for pollution removal in wetlands are sedimentation, adsorption, precipitation and dissolution, filtration, biochemical interactions, volatilization and aerosol formation, and infiltration (Strecker et al. 1992). Wetlands are useful in cleansing storm water that has accumulated pollutants from pastures and croplands, feedlots, construction sites, streets and parking lots, managed forests, and mine sites. In the late 1980s, polluted runoff contributed more than 65% of the total pollution load to U.S. inland surface waters (Environmental Protection Agency 1989). Scientists agree that wetlands serve important water quality improvement functions within the landscape, and should be factored into storm water management strategies (Olson 1992; Tetra Tech, Inc. 1992).

The water purification benefits of wetlands are particularly important in the Mississippi River Basin, where the use of farm chemicals is extremely high. In 1991, for example, more than 100,000 metric tons of pesticides and about 6.3 million metric tons of nitrogen fertilizer were applied on cropland in the Mississippi River Basin (Goolsby et al. 1993). Farmers in the Mississippi River Basin used more than two-thirds of the nearly 30 thousand metric tons of atrazine applied nationwide in 1987–89. The total atrazine load transported to the Gulf of Mexico from April through August 1993 (539,000 kg), was about 80% higher than it was for the same period in 1991 and 235% higher for the same period in 1992. According to the U.S. Geological Survey, high concentrations of herbicides combined with high river flows increased the loading of the chemicals carried by the rivers by almost 50% over previous measurements. On several days during the peak flows, for example, the Mississippi River at Thebes was carrying more than 6,000 kg of atrazine per day (Goolsby et al. 1993).

Wetlands can capture and break down atrazine. Research conducted by Wetlands Research, Inc., shows that the atrazine load carried by storm water into a tributary of the Mississippi River was almost entirely removed when detained in wetlands. Atrazine settled out of the water and was adsorbed by cattail debris, soil, and sediments after 6 to 30 days (R. H. Kadlec and H. H. Alvord 1993, unpublished data). Additional research is needed to determine if atrazine and breakdown products remain in sufficient concentrations in wetland soils to pose a future threat to water quality.

The mean annual concentration of nitrate in the lower Mississippi River has doubled since the mid-1950s (Turner and Rabalais 1991). These riverine inputs of nitrate are linked with seasonal periods of hypoxia, or oxygen deficiency, in the Gulf of Mexico off the Louisiana Coast (Justic et al. 1993). Hypoxia results in a decline in benthic invertebrates in bottom waters and a lack of other invertebrates and fish in the water column. This decline in invertebrates and fish threatens the commercially important fish species that feed on them (Coleman 1992). The annual load of nitrate transported to the Gulf of Mexico from April through August 1993 was 827,000 metric tons—112% higher than in the previous year (Goolsby et al.1993). The floodwater draining into the Gulf of Mexico from the Mississippi River in 1993 doubled the size of the hypoxic zone in comparison with previous years. In 1995, the hypoxic zone reached a record 1.8 million ha in size.

Treatment of nitrate-laden storm water by wetlands throughout the upper reaches of the basin could decrease the loads transported to the Gulf. The anaerobic, or oxygen-deficient, soils characteristic of wetlands catalyze denitrification, or the loss of nitrogen as it is converted to gaseous nitrous oxide and molecular nitrogen (Mitsch and Gosselink 1986). Wetland plants also store excess nutrients, including nitrogen, in standing biomass. Kadlec and Kadlec (1979) reported that aboveground standing wetland plants store 40 to 460 kg of nitrogen per hectare, with a mean of reported values of 207 kg/ha.

Wetlands also provide essential breeding, nesting, feeding, and refuge habitats for many species of birds, mammals, amphibians, and reptiles. Many rare life forms, including federally listed endangered and threatened plants and animals, require wetland habitats during some portion of their life cycle. Wetlands are important spawning and nursery areas and provide sources of nutrients for commercial and recreational finfish and shellfish industries.

The wetlands of the Mississippi River Basin support an important component of North America's biological diversity. The river is a major flyway for migratory birds, including as much as 40% of North America's ducks, geese, swans, and wading birds. About 60% of the bird species in the conterminous United States may be observed in the Mississippi River flyway. The Upper Mississippi National Wildlife and Fish Refuge supports about 300 resident and migratory bird species, including bald eagles (*Haliaeetus leucocephalus*) and tundra swans (*Cygnus columbianus*). Other wildlife that use the bluffs, bottomlands, and backwaters along the river include 50 species of mammals, 45 species of reptiles and amphibians, and 37 species of mussels (Sparks 1992; USACE 1988).

After more than a century of rapid wetland destruction, restoration is increasing in the basin. The prairie potholes and other midwestern wetlands historically provided extensive wildlife habitat—particularly breeding habitat for waterfowl. Much of this habitat has been lost as a result of conversion to agriculture. The NRC (1992) estimated that wetland losses in the prairie pothole region of the United States, which includes parts of North Dakota, South Dakota, Minnesota, and Iowa, may have led to a 50% reduction in populations of wetland-dependent wildlife. Weller (1981) reported that the loss of 94% of Iowa's wetlands resulted in extirpation of sandhill cranes (*Grus canadensis*), short-eared owls (*Asio flammeus*), and northern harriers (*Circus cyaneus*). Canada geese (*Branta canadensis*) and trumpeter swans (*Cygnus buccinator*) in wetter areas also have been lost from the community. Replacement of some of the wetlands that have been drained is essential to the recovery of these wildlife populations.

Soil and Water Conservation Practices

Soil and water conservation practices can contribute to flood damage reduction goals by maximizing the retention of water on the landscape, reducing soil erosion-related flood damages, and preventing premature siltation of water storage areas.

Historically, the UMRB was characterized by extensive prairie systems. The prairies were large stands of perennial grasses that formed thick root mats and contributed large quantities of organic matter to the soil. This rich soil increased the waterholding capacity of the landscape and promoted infiltration of water from the soil surface into aquifers below. The thick stands of grasses and other native vegetation also halted water as it ran off the landscape, providing additional infiltration opportunities and adding surface area for the filtration of eroded soil particles and other impurities.

The conversion of prairie communities to cultivated acreage has a number of effects on hydrology. First, under conventional tillage practices, soil may remain unvegetated and unprotected from erosive forces for large portions of the year. This condition results in rapid storm water runoff and high soil erosion rates. The top few inches of the soil, which contain the highest organic matter content, are the first to erode. Thus, the soil loses much of its moisture retention capacity. Organic matter is replaced much more slowly by annual crops, such as corn and soybeans, which are harvested after every growing cycle, than by perennial grasses, which build root systems over many years. Soule and Piper (1992) described the contribution of soil erosion to frequent and severe flooding through the soil's loss of water retention capacity, and through the silting-in of riverbeds and wetlands and the resulting loss of water storage areas.

In a portion of Wisconsin that drains to the Mississippi River, for example, the removal of native vegetation and the implementation of European farming practices in the nineteenth century dramatically altered watershed hydrology. Surface runoff and soil erosion increased greatly as many of the forests, oak savannas, and tall-grass prairies were replaced by cultivated fields. As a result, overbank flooding became more severe and the deposition of sediment on valley floors increased sharply (Knox 1977). Peak discharges in the lower Buffalo River watershed, which drains to the Mississippi River, are estimated to be 2 to 3 times as high as they were under presettlement conditions (Knox and Faulkner 1994).

The U.S. Department of Agriculture programs developed over the past decade, such as the conservation reserve, conservation technical assistance, and conservation compliance programs, have improved soil erosion control nationwide. The SCS's 1992 National Resource Inventory reflects substantial gains in soil erosion control over the past decade. The inventory reported that average sheet and rill erosion decreased from 4.1 tons per acre per year to 3.1 tons per acre per year between 1982 and 1992.

Soil and water conservation practices that increase the density of vegetation cover in a watershed (i.e., conservation tillage, no-till farming, intercropping, and short- and long-term acreage set-asides) can lower hydrographs by retaining water on the landscape. Mechanisms involved in reducing flood peaks are interception of falling raindrops, increased soil storage, greater infiltration and percolation to groundwater, and protection against surface sealing (Baker 1987; Mannering et al. 1987; Langdale et al. 1992). Soil enrichment with organic matter can provide additional flood damage reduction benefits. Hudson (1994) found highly significant correlations between organic matter content and the water retention capacity of soils.

The benefits of soil and water conservation practices for reducing flood peaks were documented by the SCS in the early 1980s in a study of the Skunk River Basin, which drains into the Mississippi River from Iowa. Conservation practices installed in the basin included conservation tillage (which requires that at least 30% of the soil surface be covered by crop residue postharvest), contouring, and terraces. The results of the Skunk River study showed a reduction in peak flows for all sizes of floods with greatest reductions for more frequent, smaller floods. The SCS concluded that land treatment alternatives would effect significant reduction in flood peaks when fully installed, with as much as a 21% reduction in the 100-year flood flow (SCS 1985).

Soil and water conservation practices also result in reduced flood damages. The Iowa Department of Agriculture and Land Stewardship (J. Gulliford, Iowa Department of Agriculture and Land Stewardship, Des Moines, 1993, unpublished data) analyzed flood damage information from the State of Iowa after the floods of 1993 to assess the effectiveness of soil and water conservation practices installed over the previous decade. Between 1984 and 1993, conservation practices, including no-till, conservation tillage, terraces, contouring, and strip-cropping were installed on about 1.6 million ha (4 million acres) across Iowa. Precipitation in 1993 was 3.4 times higher than in 1984, but cropland acres damaged by severe erosion were 40% less because much of the cropland was protected by conservation practices.

Like wetland restoration, soil and water conservation practices provide water quality and wildlife habitat benefits in addition to flood damage reduction. Conservation tillage or no-till farming, for example, can reduce quantities of chemicals that exhibit a strong tendency to adsorb to soil particles, such as organic nitrogen, phosphorus, and some pesticides in runoff, thus enhancing water quality (Logan et al. 1987). While some argue that an increase in chemical application is necessary to control weeds and insects under conservation tillage, some farmers find that pest problems actually decrease if such practices are combined with seasonal crop rotations (R. Seigel, Iowa Corn Growers Association, 1997, personal communication). Programs that pay farmers to take land out of production completely also result in water quality benefits. The initial Conservation Reserve Program (CRP) authorized in 1985 will generate an estimated $3.5 to $4 billion in water quality benefits within its lifetime (Ribaudo 1989). Increased water quality benefits are likely to result from the program as reauthorized in 1996 because the U.S. Department of Agriculture is intentionally targeting areas for enrollment based on water quality objectives. Per-acre water quality benefits from CRP are likely to be 7 times greater than those from traditional soil conservation practices because CRP targets erodible land and takes it completely out of production (Ribaudo 1989).

Agricultural conservation programs, such as the CRP, also provide substantial wildlife habitat. Nearly 4.8 million ha (12 million acres) in the prairie pothole region states of Iowa, Minnesota, Montana, and North Dakota, for example, are enrolled in the CRP—4 times the acreage in those states controlled by the state wildlife agencies and the U.S. Fish and Wildlife Service (McKenzie 1993). Studies of CRP land in Minnesota, Montana, North Dakota, and South Dakota revealed that the grassland restored through the CRP had contributed to the recovery of several breeding populations of prairie birds (Johnson and Schwartz 1993; Reynolds et al. 1994).

A combination of conservation practices and wetland restoration projects could substantially reduce flood damages, while providing a wide range of additional benefits. The existing Federal programs that assist farmers and other landowners in implementing conservation projects have never been adequately funded to meet the demand for their services. These programs could be used as building blocks in a natural storage strategy for reducing flood damages in the UMRB.

Case Study: The Redwood River Basin, Minnesota

The 179,415-ha (443,000-acre) Redwood River watershed begins on the "Coteau du Prairie," a rolling plateau punctuated with numerous small lake and wetland basins. Before agricultural drainage, wetlands covered roughly 43% of the basin. More than 82% of the watershed is now used for agriculture, indicating extensive drainage of wetlands. Before drainage for agriculture, many of the Redwood River Basin wetlands were closed basins that stored rainfall and did not contribute directly to river flows (NRC 1997). Local officials believe that increased drainage of former wetland areas in the 1970s and 1980s has led to increased flooding throughout the basin (R. Finley, Redwood/Cottonwood Rivers Control Area, Redwood Falls, Minnesota, 1995, personal communication). The headwaters of the Redwood River drain into the town of Marshall, Minnesota. Marshall, which lies on the banks of the river, experiences periodic flooding. During 1993, Marshall was flooded by three separate rainfall events that triggered floods ranging in frequency from estimated 20- to 50-year events. Lyon County, where Marshall is located, received nearly $17.5 million in Federal Aid in response to the 1993 floods, more than $14.5 million of which was for agricultural damages (Phillipi 1995).

Government agencies have planned traditional flood control projects for the basin, but the projects have faced political opposition because they would provide benefits only to the town of Marshall while imposing costs on other portions of the basin. The U.S. Army Corps of Engineers (USACE) and SCS studied the Redwood River Basin as part of a P.L. 639 river basin study of the Minnesota River in the 1970s and 1980s. This study identified several potential dam sites in the basin but found them unjustifiable on the basis of current economic guidelines used in Federal water resource planning activities. One of the P.L. 639 potential dam sites, known as Redwood 22, was then adopted by Area II Minnesota River Basin Projects, a nonprofit, joint-powers organization formed to cost-share flood control projects in the Minnesota River Basin. Area II plans to build the proposed dam on the South Branch of the Redwood River upstream of Marshall, but has encountered resistance from residents of the proposed project site. Fish and wildlife agencies have expressed concern over the project's potential effects on wetlands and on a state wildlife management area and have encouraged Area II to consider a comprehensive approach to flood damage reduction. They are presently working with Area II to get a better understanding of effects on wetlands and find ways to avoid or minimize them. The USACE has produced a plan for a project that would divert water from the Redwood River at Marshall to nearby Cottonwood River during high flood stages. Stage 1 of this project (modifying the existing channel) has been funded but stage 2, which involves the construction of the diversion culverts, is facing resistance from residents of the Cottonwood River Basin.

The study of the Redwood River Basin published by the Scientific Assessment and Strategy Team (1994) indicated that if all depressional hydric soil units in the subbasin were restored to wetland (roughly 19% of the watershed), the average peak reduction for 124 subareas within the subbasin would be 53%. This percentage decreases as runoff from subareas is combined and routed downstream. Restoration of 25% of the depressional hydric soils (5% of the watershed) would result in an average peak reduction of 36% for the 124 subareas. According to the model, restoration of all depressional soil units and prevention of surface water discharge during rainfall events from half of them would reduce the 100-year flood peak at the mouth of the river by 16% (Cooper 1994). The model results indicated that further investigation of a wetland restoration strategy for reducing flood damages in the Redwood River Basin was worthwhile. Over the past 3 years, therefore, the Natural Resources Conservation Service, in cooperation with state agencies, has been building a more intensive modeling and monitoring effort for the basin.

The Redwood River Basin is in the midst of prairie pothole country, and is therefore of high priority for the restoration of continental waterfowl populations. The Redwood River drains into the Minnesota River Basin, an extremely high priority area for water quality improvements in the state of Minnesota. These characteristics increase the attractiveness of the Redwood River Basin for state and Federal funds aimed at wildlife restoration and water quality enhancement.

A number of local, state, and Federal agencies and organizations are presently investigating the potential for wetland restoration and soil and water conservation practices to contribute to flood damage reduction and other goals for the Redwood River. Citizens are being consulted and recruited to assist in this effort. If successful, the Redwood River Water Management Project will result in a wide range of benefits to basin residents.

Implications for Management of the Upper Mississippi River Basin

A number of events are conspiring to effectuate a holistic approach to management of the Mississippi River. The consolidation of the USACE District Offices along the river into a single Mississippi Valley Division may increase collaboration between the upper and lower ends of the watershed. The creation of an “Upper Mississippi Summit,” which is providing a venue for a wide range of agencies and interest groups to discuss river management issues, has the potential to integrate environmental objectives with navigation and flood damage reduction objectives in the upper basin. The Clinton Administration's American Heritage Rivers initiative is inducing dialogue between mayors in river towns from St. Paul, Minnesota, to Cairo, Illinois. The World Wildlife Fund's Mississippi/Rhine/Danube exchange program is bringing together river managers from the headwaters to the delta of these large rivers in an attempt to promote integrated approaches to management. The ongoing navigation study and upcoming Congressional review of the Environmental Management Program (EMP) also provide venues for broad discussions regarding management of river basin resources. In an era with increasing occasions for dialogue among the broad range of interests involved in river management, opportunities for wetland restoration and watershed management designed to provide a wide range of benefits are abundant.

The EMP could play a substantial role in the holistic management of the UMRB, including a natural storage approach for flood damage reduction. The Environmental Management Technical Center (EMTC), which coordinates implementation of the EMP, has developed the capacity to collect, analyze, map, and create geospatial databases from information critical to the ecological health of the Upper Mississippi River watershed. This capacity could be productively used to identify watershed sources of excessive runoff and pollutants as well as restoration opportunities.

Scientists and river managers are encouraging the EMTC to broaden its data collection and analysis efforts to include watershed processes. The Science Review Committee (1996), convened to review the EMTC's Long Term Resource Monitoring Program, recommended that the EMTC conduct a detailed quantification of input into the river systems and help identify basin problems that need to be addressed to help to maintain and improve river conditions. The draft report to Congress on the EMP prepared by the USACE Rock Island District (1997) suggests that the EMP should expand its involvement in watershed management issues. The draft report contains a number of alternatives for the future of the EMP. Among these is a "Coordinated Basin Management Alternative," which would include separate management components for the river, floodplain, and watershed. The watershed component would have the development of a coordinated approach to the environmental aspects of multiobjective watershed management as its first task. In developing this approach, the EMP would consider aspects of agricultural conservation programs, tributary streams and riparian areas, and wetland restoration for flood protection.

The draft report states that, at the watershed level, the most promising approach toward understanding of the relations between land use and its effects on erosion, sedimentation, water quality, and water quantity is through Geographic Information Systems modeling. Many of the tools needed for the development of multiobjective watershed management plans have been or are being developed by agencies active in Mississippi River management. The EMTC has aready begun to study the relations between the watershed and the river, partly to assess alternatives for managing the zone of hypoxia in the Gulf of Mexico (P. H. Gowda and D. A. Olsen, EMTC, Onalaska, Wisconsin, 1997, personal communication).

Watershed management with the goal of restoring hydrologic processes should be an important component of a long-term strategy for flood damage reduction and environmental management in the UMRB. Upper Mississippi River Basin communities and private organizations are increasingly working with Federal, state, and local agencies to implement projects that will demonstrate the effectiveness of wetland restoration projects and soil and water conservation practices in reducing flood damages, improving water quality, and creating or restoring wildlife habitat. Existing programs and authorities, such as the U.S. Fish and Wildlife Service's Private Lands Program and North American Waterfowl Management Plan, the Environmental Protection Agency's Section 319 nonpoint source pollution and wetlands programs, the USACE Section 22 Planning Assistance to States and Floodplain Management Assistance Programs, and local floodplain ordinances and greenway creation projects, are being used to implement the projects.

Conclusion

An approach to reducing flood damages that focuses on natural storage rather than rapid conveyance of storm water could produce a wide range of benefits in a cost-effective manner. Many of the policy tools necessary for implementing a natural storage approach already exist, but remain underfunded, uncoordinated, and poorly targeted. Decision makers at the Federal, state, and local levels are beginning to evaluate the benefits and costs, as well as the effectiveness, of implementing a natural storage approach to flood damage reduction.

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REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE August 1997	3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE A natural storage approach for flood damage reduction and environmental enhancement	5. FUNDING NUMBERS
6. AUTHOR(S) Constance E. Hunt	
7. PERFORMING ORGANIZATION NAME AND ADDRESS World Wildlife Fund 1250 24th Street, NW Washington, D.C. 20037	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Geological Survey Environmental Management Technical Center 575 Lester Avenue Onalaska, Wisconsin 54650	10. SPONSORING/MONITORING AGENCY REPORT NUMBER 97-S005

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT Release unlimited. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 (1-800-553-6847 or 703-487-4650. Available to registered users from the Defense Technical Information Center, Attn: Help Desk, 8725 Kingman Road, Suite 0944, Fort Belvoir, Virginia 22060-6218 (1-800-225-3842 or 703-767-9050).	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The frequency and severity of flooding in the Upper Mississippi River Basin is influenced by three major factors: the amount and timing of precipitation, the condition of the basin's stream channels and floodplains, and the timing and rate of storm water conveyance off the watershed, which is a function of soil condition, extent of impervious surface, vegetation density, and other factors. To the extent that changing precipitation patterns result from human-caused changes in the global climate, this factor can be addressed through international efforts to reduce emissions of greenhouse gases. Careful planning and design can provide some control over the condition of channels, floodplains, and watersheds. The primary strategy employed by the United States and other developed nations for reducing flood damages has been to maximize the conveyance of storm water downstream and structurally alter channels and construct levees to protect adjacent communities from floods. Since the land behind 100-year levees was protected from flood stages with an annual probability of occurrence less than or equal to 1%, development was frequently allowed to occur on lands that would otherwise be within the 100-year floodplain, with no additional requirements for flood insurance or flood protection. An emerging approach to flood damage reduction retains water on the upland landscape and focuses on allowing historical floodplains to again provide storage and conveyance benefits for reducing flood peaks. Floodplains under this approach are used for storing and conveying floodwaters, and also function as water filters and habitat for fish and wildlife. To the maximum extent possible, vulnerable structures are removed from the 100-year floodplain. This approach is referred to as the "natural storage" approach.

14. SUBJECT TERMS Environmental enhancement, floodplains, natural storage, Upper Mississippi River Basin, watershed	15. NUMBER OF PAGES 16 pp.
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

The Long Term Resource Monitoring Program (LTRMP) for the Upper Mississippi River System was authorized under the Water Resources Development Act of 1986 as an element of the Environmental Management Program. The mission of the LTRMP is to provide river managers with information for maintaining the Upper Mississippi River System as a sustainable large river ecosystem given its multiple-use character. The LTRMP is a cooperative effort by the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin.