Commentary

Flood Reduction through Wetland Restoration: The Upper Mississippi River Basin as a Case History

Abstract

Despite this nation's massive effort during the past 90 years to build levees throughout the upper Mississippi Basin, mean annual flood damage in the region has increased 140% during that time. These levees exacerbate the flood damage problem by increasing river stage and velocity. Thus, rather than continuing to rely on structural solutions for flood control, it is time to develop a comprehensive flood management strategy that includes using wetlands to intercept and hold precipitation where it falls and store floodwaters where they occur. History testifies to the truth of this premise: it was the rampant drainage of wetlands in the nineteenth century that gave rise to many of today's water resources management problems. The 1993 flood verifies the need for additional wetlands: the amount of excess water that passed St. Louis during the 1993 flood would have covered a little more than 13 million acres—half of the wetland acreage drained since 1780 in the upper Mississippi Basin. By strategically placing at least 13 million acres of wetlands on hydric soils in the basin, we can solve the basin's flooding problems in an ecologically sound manner.

A flood is one of the last stages in the hydrologic cycle, which begins when precipitation forms and falls to earth. Yet it is only at the last stage that we attempt to control and solve the problem confronting us: damage caused by flooding. Since the early nineteenth century, we have largely relied on levees to hold floodwaters back. It is only more recently that we have seen the need to control the damage less by structural restraints than by managing development on floodplains.

It is time we took a further step in our policy, our programs, and our thinking about floods, a step back, actually, through the hydrologic cycle to the early stages when precipitation first reaches the surface—any surface—of the watershed. We need to begin to build a national strategy to hold the drop of rain or flake of snow where it falls. This is not a new idea, but its implications for a management strategy have not yet been taken seriously. This paper provides some ideas on how such a strategy would work.

The Flooding Paradigm

Until 300 years ago, when precipitation descended from the skies of North America it was intercepted by thick layers of vegetation, organic-rich soils, and lush depressional areas called wetlands. A large portion of the water was trapped in these wetlands and retained in the soil or returned to the atmosphere through evaporation. A small portion trickled over intercepting surfaces, gradually forming streamlets and then creeks, the surface movement affected along the way by hydraulic gradient and numerous obstacles, such as beaver dams and debris. Swelled by snowmelt in springtime, the creeks and streams spread out across the wetlands. When these waters finally reached the mainstem rivers, they spread out harmlessly across wide floodplains, which held and slowed their movement until they evaporated, infiltrated the soil, or gradually withdrew back into the rivers' channels.

As European trappers and settlers moved across the land, they changed all that. Intercepting vegetated surfaces were chopped down or plowed under. Forests and prairies were replaced by row crops and pastures, which reduced interception and subsequent storage of the water. Impervious rooftops and road surfaces were built, increasing the amount of runoff. Beaver were extirpated and their dams removed or washed out. Across the continent, more than half of the beaver ponds and marshes, which had trapped and held floodwaters, were destroyed. The vegetation and debris that had clogged the swales and sloughs were cleared away, no longer impeding floodwaters. For faster drainage or better navigation streams were dredged, straightened, and deprived of meander loops, which had slowed the flow of water. The heavy springtime flows were also denied access to the storage areas of last resort—the natural floodplain. Constrained by levees, which had been all too often overtopped, floodwaters have increased in depth, flood damage has increased, rendering the levees useless.

For the past 175 years, our flood control efforts and dollars have been invested in the construction of channel-restricting levees, encouraging crops to be grown and homes, industries, and even cities to be built behind them. Yet, as the elevation and the force of flood flows increased, that same development brought about an increase in flood damage when the levees eventually failed—as did 1000 levees along the upper Mississippi and Missouri rivers in the summer of 1993.

We know that flood damage has been increasing steadily, even as we have been building higher and bigger levees throughout the Mississippi Valley (Fig. 1). The mean annual damage has increased from $1.4 billion in the first 30 years to $3.4 billion in the most recent 30 years—a rise of 140%. The 1993 flood waters caused $16 billion in damage as they spread out over the landscape (Exhibits 1 and 2).

We could try to build ever stronger, higher levees, but perhaps it is time to change our focus to a more effective, comprehensive flood management strategy. We can start by returning a small portion of the watershed to its native, vegetated state. We can restore—at least in part—a prairie-forest matrix to intercept and hold the precipitation where it falls. We can increase the water-holding capacity of our soils by replenishing their organic content. We can expand the surface-holding capabilities of wetlands, not to the exclusion of agricultural production but in association with that production. Restored riverine and palustrine wetlands could be distributed strategically throughout the watershed.

Such a strategy is not impossible, unreasonable, or even expensive. It

Exhibit 1. Non-flood stage. Mississippi and Missouri Rivers confluence area under normal flow conditions. Missouri River, the smaller, meandering system, below the braided Mississippi. City of St. Louis, MO lower center, with Mississippi River to the east. Agricultural land on the flood plain between 2 river systems. State of Illinois north of Mississippi River, Horseshoe Lake lower right. July 4, 1988. 2,000 feet. GEOPIC®, Earth Satellite Corporation.

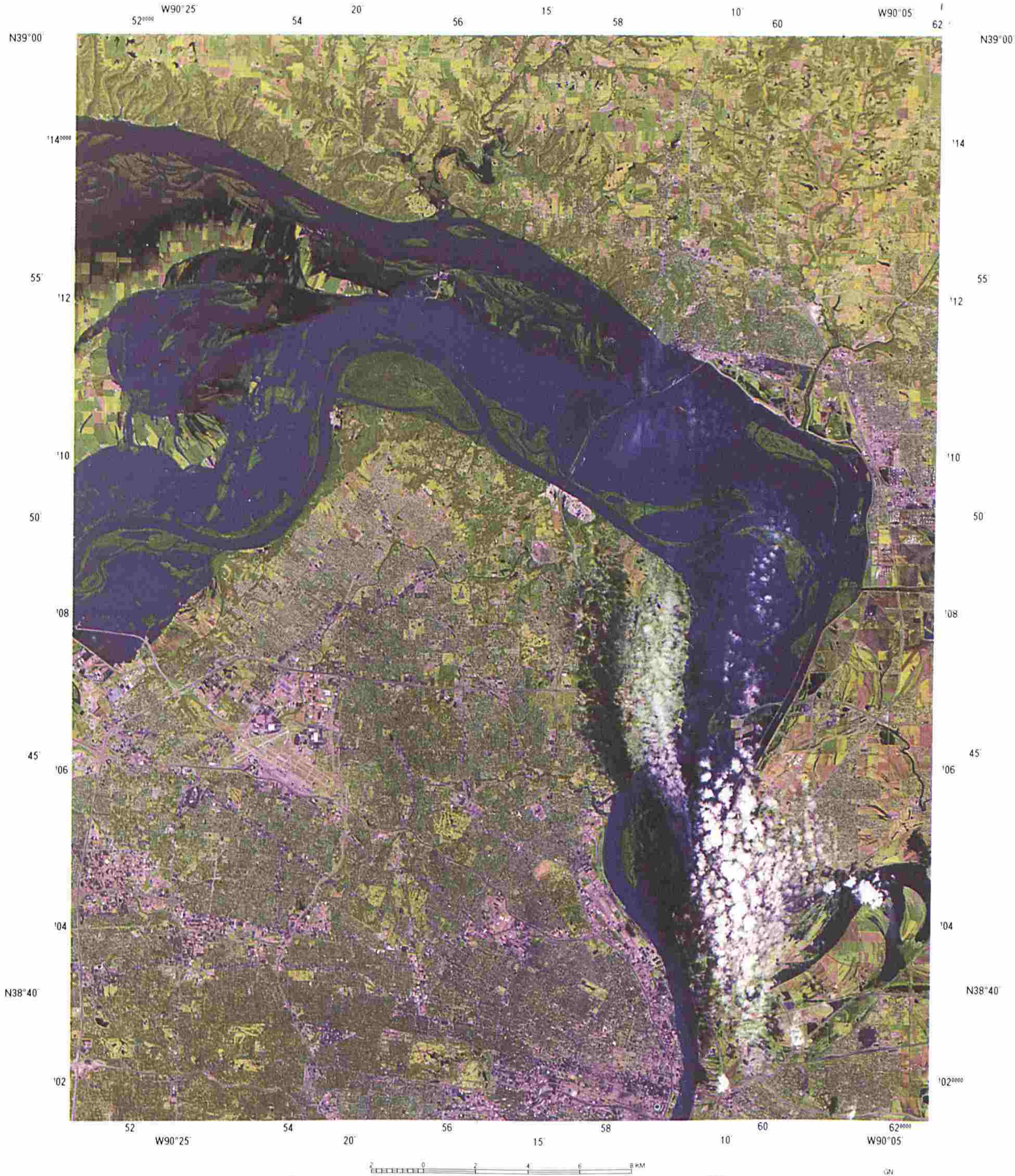

Exhibit 2. Flooded stage. Mississippi and Missouri Rivers join together in flooding agricultural land between river systems. Dome-shaped Pelican Island green, evident in meander of Missouri River. Clouds white and cloud shadows black along the Mississippi, lower right. July 18, 1988. 2,000 feet. GEOPIC®, Earth Satellite Corporation.

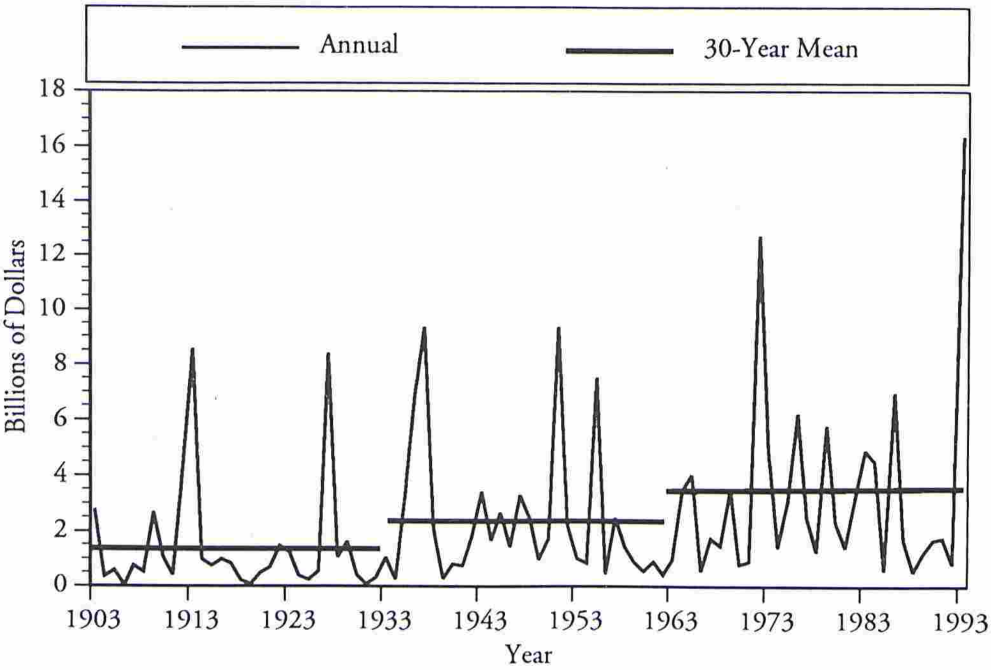

Figure 1. National annual and 30-year mean flood damages, adjusted to 1993 dollars (source: U.S. Weather Bureau).

would not require a large bureaucracy to implement but rather a small cadre of scientists, engineers, and educators. Perhaps as little as 4% or 5% of any watershed would have to be restored, no more than already exists as idle agricultural land in the upper Mississippi Basin (Hey et al. 1994; Fig. 2). Such a land area, it appears, could have easily contained most of the floodwaters that devastated the valley in 1993.

The 1993 Flood in Context

The immediate cause of the 1993 floods along the upper Mississippi and Missouri rivers was widespread, heavy rainstorms across the eastern por-

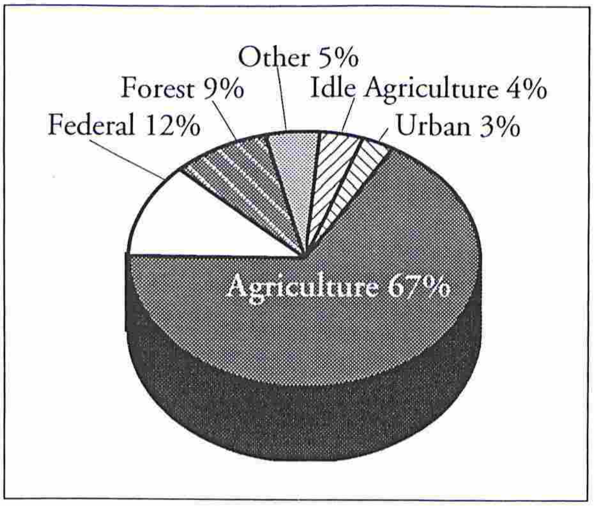

Figure 2. Current land use and land cover in the upper Mississippi and Missouri River basins (source: Bureau of Census 1990).

tion of the basin in June and July, falling on a watershed already saturated by spring snowmelt and rains. Anyone who watched the billowing crests of brown water surging over the levees and across the farmland of Missouri and Iowa could not seriously imagine that a bigger levee alone could have held them back. Levees became part of the problem by increasing river stage and velocity. They created a river channel incompatible with the climate, land use, and hydrology of the basin.

The drainage patterns of the modern Mississippi River were formed gradually over 10,000 years by varying climatic and hydrologic conditions and the interaction of precipitation, topography, soils, vegetation, and wildlife. The river channels designed themselves in response to various combinations of these factors. One of the most ubiquitous and important design features was wetlands. In 1823, W. H. Keating, a member of General Long's expedition to the source of the Minnesota River, described the eastern edge of the watershed near Fort Wayne, Indiana, as

> . . . so wet that we scarcely saw an acre of land upon which settlement could be made. We travelled for a couple of miles with our horses wading through the water, sometimes to the girth. Having found a small patch of grass . . . we attempted to stop and pasture our horses but this we found impossible on account of the immense swarms of mosquitoes and horse flies. . . . [We found] the region southwest of Chicago covered in water as well; . . . from Chicago to a place where we forded the Des Plaines River, the country presents a low, flat and swampy prairie, very thickly covered with high grass, aquatic plants, and among others, the wild rice. The latter occurs principally in places which are under water; its blades floating on the surface of the fluid like those of the young domestic plant. The whole of this track is overflowed during the spring, and canoes pass in every direction across the prairie. (Wooten & Jones 1955).

These conditions were not to last much longer. By the late 1600s, Europeans had begun to intervene, tinkering with nature at increasing risk to themselves. The first and perhaps the most dramatic alteration of the watershed's hydrologic cycle was brought about by the fur trade. Prior to trapping, the estimated beaver population was somewhere between 10 and 40 million (Seton 1929). At these densities, beaver probably exerted direct control over smaller streams, up to and including fourth-order streams. On these streams, they built dams 400 to 500 feet apart (Hamilton 1939). By 1843, the beaver was considered nearly extinct in Illinois (Oliver 1843). As beaver dams washed out, they were not replaced. In many cases, they were deliberately removed to promote drainage. Flood storage was thereby greatly reduced and stream velocities greatly increased.

By the 1850s, agricultural development was in full swing in the watershed. Little or no prairie or forest was saved from the plough. A mighty agricultural industry developed, not in the prairie but over it. As prairie soils were turned over and their carbon content reduced by erosion and oxidation, the water-holding capacity of the soils was diminished. To support domesticated crops and to extend agricultural development into such hostile environments as wetlands, outlet ditches were constructed and tile drains installed. More than 155,000 miles of outlet ditches were built across the country (Wooten & Jones 1955), a disproportionate number of these in the eastern half of the Mississippi Basin due to the heavy, poorly-drained soils. These ditches, straight and clear of retarding vegetation, emptied the tile fields quickly and hastened the water downstream. More than 8000 drainage districts were eventually organized, draining more than 50 million acres in the Midwest alone (Lant & McCorvie 1993).

The ubiquitous wetlands were viewed as impediments to economic activity and the development of rich bottomlands along the mainstem rivers. In 1848, the Swamp Land Acts transferred 100,000 acres of Mississippi floodplain to the states for conversion to farmland by drainage and levee construction. As markets and industrial centers developed, the need for better, more efficient urban drainage was recognized. Elaborate storm-sewer systems were put in place to dispatch urban runoff into local streams which, unable to hold the increased flow, inevitably required dredging, straightening and, in many cases, concrete linings to move the water — and the problem — downstream.

The solution soon became part of the problem. This ad hoc attempt at redistribution of floodwaters from the upper to the lower basin produced more frequent floods of greater magnitude. As the yield of the deforested, agriculturalized, and urbanized basin increased by two- to three-fold, the scourge of flooding spread across the Mississippi Basin, affecting small and large floodplains alike. Although the first comprehensive, national flood control act was not passed until 1936, levee construction on the upper Mississippi, usually in the name of navigational improvements, had begun in the early 1800s. It intensified in the latter part of that century. Then, in 1927, after floodwaters drove 700,000 people from their homes, Congress passed the largest public works expenditure in our history: $325 million for flood control works on the lower Mississippi.

In 1852, in response to Mississippi delta flooding, Congress appropriated $50,000 for two studies: the first recognized how man-made intrusions (namely, cultivation and levees) intensified flooding; the second called for even more levees to stop the flooding. The first was written by Charles Ellet, Jr. (1852), an engineer who understood the hydraulics of the river and hydrology of the watershed. In his report to Congress, he wrote:

> . . . the causes of the more frequent and more extensive overflows of the delta of the Mississippi, in recent than in former times, are considered, and plans suggested for the mitigation of the evil. The greater frequency and more alarming character of the floods are attributed —
>
> *Primarily*, to the extension of cultivation, throughout the Mississippi Valley, by which the evaporation is thought to be, in the aggregate, diminished, by the drainage obviously increased, and the floods hurried forward more rapidly into the country below.
>
> *Secondly*, to the extension of the levees along the borders of the Mississippi, and of its tributaries and outlets, by means of which the water that was formerly allowed to spread over many thousand square miles of low lands, is becoming more and more confined to the immediate channel of the river, and is, therefore,

> compelled to rise higher and flow faster, until, under the increased power of the current, it may have time to excavate a wider and deeper trench to give vent to the increased volume which it conveys.
>
> *Thirdly*, to cut-offs, natural and artificial, by which the distance traversed by the stream is shortened, its slope and velocity increased, and the water consequently brought down more rapidly from the country above, and precipitated more rapidly upon the country below.
>
> *Fourthly*, to the gradual progress of the delta into the sea, by which the course of the river, at its embouchure, is lengthened, the slope and velocity there are diminished, and the water consequently thrown back upon the lands above.
>
> It is shown that each of these causes is likely to be progressive, and that the future floods throughout the length and breadth of the delta, and along the great streams tributary to the Mississippi, are destined to rise higher and higher, as society spreads over the upper States, as population adjacent to the river increases, and the inundated low lands appreciate in value.

Ellet, however, was ahead of his time. The second study, *Report Upon the Physics and Hydraulics of the Mississippi river*, was prepared by Captain Andrew A. Humphreys, later to become Chief of Engineers, and Lieutenant Henry L. Abbot. It endorsed levees as the only appropriate flood damage prevention technique (Arnold 1988). This became the foundation of the Mississippi River flood control strategy for the next 140 years.

Other voices, however, have echoed Ellet's conclusions. According to a report published by the Illinois Division of Waterways in 1929 (1929), "The practical effect of building levees on the Illinois River has been to increase the stages and prolong the duration of high water." The report contained an interesting analysis of flood flows and stages from 1844 to 1926, showing an inverse relationship between stage and discharge over this period, indicating that levees increased the stage for a given discharge.

By 1937, the Division of Waterways (1937) was becoming increasingly frustrated with the repeated flood losses and increasing flood damage:

> Absolute protection against floods cannot be assured beyond all doubt. Therefore, when bottom lands are cultivated some risks must be assumed and is the penalty that must be paid for taking the bottomlands from the floodway of the river. Flood losses should be provided for by a regular fixed charge in the operation of the district [drainage and levee] by an insurance plan.

Again in 1950, an objection to the use of levees was raised. The Illinois Department of Conservation (1950) proposed the restoration of selected floodplains and rivers and opposed the construction of levees, writing:

> As early as 1915 when only half of the present levees had been built, the Illinois Rivers and Lakes Commission had reported that the farm levees were a menace in that they caused floods to rise to higher levels. They were also responsible in large measure

> for the ruination of the hunting and fishing grounds along the Illinois River. For most practical purposes this report was filed and largely forgotten. . . . And now the State is confronted with a tentative plan of the Federal Government to raise most of the levees again, to repair several of those which have been repeatedly washed out by floods, and to build new levees where none exist today.

The flood of 1993 has again stimulated debate over the effects of levees on flooding and flood damage. It is still being argued that the levees did not increase flood damage. Yet J. G. Sutton, a long-time drainage engineer and employee at the U.S. Department of Agriculture, summed up the case against relying on levees for flood control. Sutton wrote (1995),

> They [levees] have some disadvantages. The flood height along the stream channel, the rate at which the floodcrest moves downstream, the maximum discharge for some distance downstream and the stream velocity and tendency for erosion to occur are all increased when floodwaters are confined between levees. Flood storage is reduced.

Designing the Solution

Rather than continuing the argument for ever-increasing levees, we could use our energy and money more productively by designing new and better solutions to the problem. The most effective and efficient solution to the flooding in the Mississippi Valley and elsewhere is control of precipitation where it first falls. At every opportunity, the natural vegetation should be rethought, redesigned, and restored. If impervious surfaces cannot be designed to intercept and detain precipitation, aprons and buffers should be designed and built to trap runoff and retain it until the evaporative or infiltration processes have time to work.

The entire soil structure of the basin needs to be considered. Over the past 150 years, we have lost as much as 70% of the water-holding capacity of our soils (Brady 1990). This capacity needs to be restored. Agricultural practices need to focus on the retention of organic material in the top 18 to 24 inches of the soil. Conservation tillage will help, but more dramatic means are needed. The use of compost and long-term prairie rotation should be explored.

Our drainage practices need to be applied more selectively and designed to address specific crop production, flood control, and wildlife needs. Tile fields undoubtedly will continue to be needed for many of our soils and landscape settings, but they can be designed to bypass critical reaches through the selective use of outlet ditches. We should be able to find sufficient land to create nodes within our drainage system where excess runoff can be stored and used for other purposes. Such purposes might include the cultivation of wild rice, marsh hay, or timber for paper pulp. They also may include hunting, fishing, and recreation. Or, more practically, we might simply use these wetlands as runoff storage nodes for efficient treatment of urban or agricultural wastewater. Proceeding from first-order to second- and third-order streams, palustrine and riverine wetlands should play an increasingly important role in the drainage system and in flood prevention.

The key to successfully implementing these solutions is in the strategic placement and scale of wetland restoration by reference to flood damage reduction needs. Effective siting of specific restoration projects can be facilitated by studying existing soil and hydrologic characteristics. The remaining hydric soils, which typically underlie our drainage systems and are found in almost every landscape, are the footprint of past beaver ponds and wetlands. The hydric soils in the basin have been greatly reduced by oxidation and erosion; nevertheless, they still exist in significant quantities. By low-scale engineering techniques, just short of using beaver to once again construct their dams, the flood storage capability of these soils can be greatly expanded.

Principles in Practice

Applying these principles to the realities of a watershed is not simple, of course. Such an application must consider the distribution, magnitude, and frequency of floodwaters generated, and how these factors relate to the land, land uses, and specific locations within the basin. According to the Army Corps of Engineers, 111 million acre-feet of water passed St. Louis during the 80 days of flooding in 1993 (Dyhouse, personal communication). Given that, at this location on the river, the bank-full discharge is 450,000 cubic feet per second, the volume of water in excess of this discharge for the 80-day flood period was approximately 40 million acre-feet. Distributed at a three-foot depth (the approximate depth of a deep marsh), these waters would have covered a little more than 13 million acres. The 26 million acres of wetlands eliminated since 1780 could have easily accommodated this volume (Table 1).

The loss of wetlands is only one of many significant changes that have occurred in the upper Mississippi Basin. Beaver populations have been reduced from perhaps 40 million to less than one million, while the human population has exploded to nearly 40 million. Land uses have changed accordingly. The basin – once dominated by prairie, forest, and wetlands – today is dominated by cropland, pasture, and range, which, along with idle farmland, accounts for more than 75% of the land uses (Fig. 2). Including urban development, we have actively manipulated over 80% of

Table 1. Measures of the original and lost storage capacity of the Upper Mississippi and Missouri River basins.

Year	*Water Surface Area (Acres)*	*% of Watershed*[a]
Beaver Ponds		
1600	51,100,000	11
1990	511,000	0.1
Lost	50,600,000	11
Wetlands		
1780	44,700,000	10
1980	18,900,000	4
Lost	25,800,000	6

[a] These figures are based on the watershed above Thebes, Illinois, which comprises 456 million acres.

the landscape. It is only in the far western and northern reaches of the watershed that land surfaces maintain, to some degree, the original drainage network and are unaffected by the annual cycle of crop production and runoff from impervious surfaces.

There are several indicators of the original storage capacity of the basin, each offering a different perspective:

Beavers. Forty million beavers in 1600 would have maintained 51 million acres of water surface, accounting for 11% of the 456 million acres of land in the upper Mississippi Basin. In contrast, the current beaver population may pond only about half a million acres. At a depth of three feet, the original ponded area could have stored more than three floods the size of the 1993 event.

Wetlands. Another perspective on the natural flood-control capacity of the basin is provided by Dahl's (1990) estimate of wetlands in the upper Mississippi Basin in the 1780s as compared to the 1980s. Based on these estimates, 45 million acres, or 10% of the basin, would have been classified as wetland in 1780. By 1980 the wetland acreage had been reduced to under 20 million acres, accounting for only 4% of the basin. The 25 million acres of drained wetland could have provided sufficient area to store two times the amount of floodwater that passed St. Louis in 1993.

Soils. It is the topsoil that contains the highly absorbent organic materials capable of holding precipitation where it falls. Unfortunately, agricultural drainage has promoted the erosion of topsoil and its conveyance downstream. As the organic content of topsoil has been removed, the water-holding capacity has been reduced. In its original state, the soil held 0.31 inches of water per inch of soil; in an eroded state, it holds 0.04 inches per inch. The basinwide capacity to hold water in the top 18 inches of soil has thus been reduced by almost 18 million acre-feet, 45% of the flood volume of 1993.

The footprints of the solution are the hydric soils. Soils surveys conducted over the last few decades show more than 40 million acres of hydric soil in the basin (Clark, personal communication), accounting for almost 9% of the surface area. This acreage matches the range of both the estimated area of presettlement wetlands (45 million) and early beaver ponds (51 million) (Table 2). Storage sufficient to capture and hold water of the magnitude of the 1993 flood could be provided by restoring 13 million acres, half of the wetlands lost since 1780. Added to the existing 19 million acres, the resulting 32 million acres of wetlands would account for only 7% of the surface area. From another perspective, this amount of restoration roughly would equal a quarter of the original beaver ponds. If implemented, this restoration proposal would account for the use of only a third of the existing hydric soils in the basin.

Hydrologically, of course, this argument is incomplete. The key to the effectiveness of an additional 13 million acres of flood storage is in its location. Storage areas will need to be selectively sited throughout the basin to achieve the greatest flood reduction benefits. Given that each precipitation event has its own peculiar pattern or distribution, many flood scenarios will need to be considered. Still, there are indications that such

Table 2. Indicators of early storage surfaces and wetland storage potential in the Upper Mississippi and Missouri River basins.

	Water Surface Area (In Millions of Acres)	*% of Watershed*[a]
Early Storage Surfaces		
Hydric Soils (1940)	41	8.9
Wetlands (1780)	45	9.8
Beaver Ponds (1600)	51	11
Wetlands		
Existing (1980)	19	4
Restorable	13	3
Total	32	7

[a] These figures are based on the watershed above Thebes, Illinois, which comprises 456 million acres.

a strategy could work. In the 1930s, for instance, beaver were used to control floods in the Pacific Northwest. As reported by Hamilton (1939),

> With the thought that beavers would regulate the flow by virtue of their many dams, a number of beavers have been introduced into areas where flood and drought conditions prevail. These animals have proved most effective in their efforts.

We can do better, however, than the beavers did. They ponded millions of acre-feet according to their own needs. Our needs are different. If we are to capture any given distribution of floodwaters, we must develop storage strategically throughout the basin. Generating the figure of 13 million acres involved some facile number crunching which, nevertheless, points the way to a feasible solution. The hard work—producing the hydrologic assessments and computer analyses—remains to be done, and we should begin today. It may take more than 13 million acres of wetlands; it will, however, take far less than the 51 million acres of beaver ponds to solve the flooding problems of the Mississippi basin in an ecologically sound matter.

Beyond Flooding

Flood damage is only one of the problems created by the present land uses and management practices of the upper Mississippi River basin; surface-water quality is another. Plagued generally by high turbidity, excess nutrients, and toxic substances, the basin's surface-water quality was exacerbated by the flood of 1993, with effects as far away as the Gulf of Mexico (Goolsby et al. 1993). Such problems would be dramatically reduced by the proposed flood-control strategy.

In addition to providing essential flood control, wetlands can act as effective water treatment basins. Based on research done at the Des Plaines River Wetlands Demonstration Project, a conservative hydraulic loading rate, yet one sufficient to accomplish substantial improvement in water quality, would be 0.083 cubic feet per second per acre (Hey 1994). At a three-foot depth, theoretically, this would provide a detention time of more than 18 days, or six days at a one-foot depth. Treating the mean flow of the Mississippi, as recorded at Thebes, Illinois, would require a modest area of close to 3 million acres in wetlands (Table 3). If the mean

Table 3. Area needed in wetlands to improve surface water quality in the Upper Mississippi and Missouri River basins as measured at Thebes, Illinois.

	Cubic Feet/ Second	*Treatment Area (Millions of Acres)*[a]	*% of Watershed*
Mean Flow	198,000	2.4	0.5
Mean Annual Flood Flow	487,000	5.9	1.3
100-Year Flood Flow	1,100,000	13.3	2.9
1993 Flood (at 3 foot depth)		13.2	2.9

[a] Based on a permissible loading rate of 0.083 cfs/acre, as established at the Des Plaines River Wetlands Demonstration Project, Wadsworth, Illinois.

annual flood flow were to be treated, assuming the same loading rate, close to 6 million acres would be needed. If the 100-year flood flow, as recorded in 1993, were to be treated, 13 million acres would be required. This is approximately the same number required for storage of the flood volume at a three-foot depth.

Numerous other benefits would accrue. This same acreage would provide significant benefits to wildlife. Conservation of the organic content of topsoil has agricultural benefits such as reduced erosion and increased soil moisture. Riverine wetlands located adjacent to major rivers would provide recreational and aesthetic assets of national significance. This kind of land-use management preserves environmental resources and justifies our country's international leadership role in the preservation of rain forests, protection of the ionosphere, reduction of greenhouse gases, and implementation of other sensitive conservation strategies.

Floods are natural phenomena. From the history of the underlying natural processes and the footprints on the land itself, we can learn best how to live with them.

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