REINVENTING A FLOOD CONTROL STRATEGY

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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 the last stage at which we attempt to control and solve the problem confronting us: damages caused by flooding. Since the early 19th century, we have largely relied on levees to hold floodwaters back. It is only more recently that we have seen the need to control those damages 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. It's not a new idea, but its implications for a management strategy have not been taken seriously. This paper provides some ideas on how such a strategy would work.

THE FLOODING PARADIGM

Up 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 and retained in the soil or returned to the atmosphere through evaporation. A small portion trickled over intercepting surfaces, gradually combining to form 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 wetlands—the landscape hallmark of North America. When these waters finally reached the mainstem rivers, they spread out benignly across wide floodplains which held and slowed their movement until they evaporated, infiltrated the soil or gradually withdrew back into the channel.

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 storage and the water-holding capacity of the underlying soils. Impervious rooftops and road surfaces were built, increasing the amount of runoff. Beaver were extirpated and their dams removed or washed out. More than half of the beaver ponds and marshes, which trapped and held floodwaters, were destroyed. The vegetation and debris, which clogged the swales and sloughs, were cleared away, no longer impeding floodwaters. Our streams were dredged and straightened for faster drainage or better navigation and deprived of meander loops, which also slowed the flow of water. The heavy springtime flows lost access to the storage areas of last resort—the natural floodplain. Constrained by levees, which have been all too often overtopped, floodwaters increased in depth and flood damage increased, as if the levees had never been built.

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 became flood damage when the levees eventually failed—as did 1,000 levees along the upper Mississippi and Missouri rivers in the summer of 1993.

We know that flood damage has been increasing steadily (Figure 1), even as we have been building higher, bigger levees throughout the Mississippi Valley. The mean annual damage has actually increased from $1.4 billion in the first 30 years to $3.4 billion in the most recent 30 years—a rise of 140 percent. The 1993 floods caused $16 billion in damage.

We could try to build those levees even stronger, even higher, but perhaps it is the time to change our focus to a more effective, comprehensive flood management strategy; or 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, un-

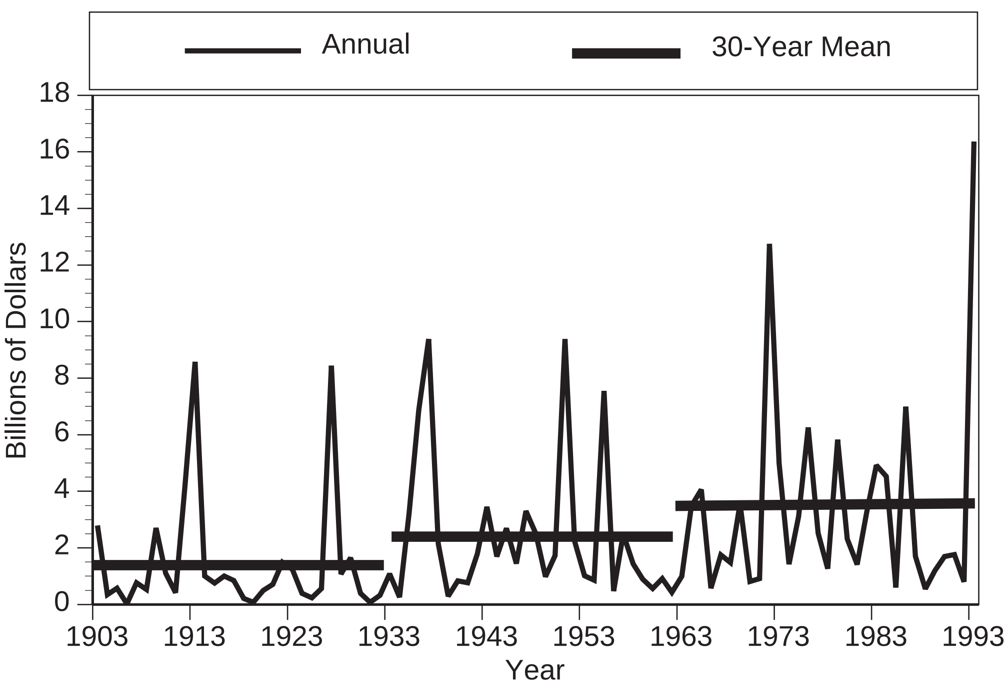

FIGURE 1. *National annual and 30-year mean flood damages, adjusted to 1993 dollars (Source: U.S. Weather Bureau).*

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

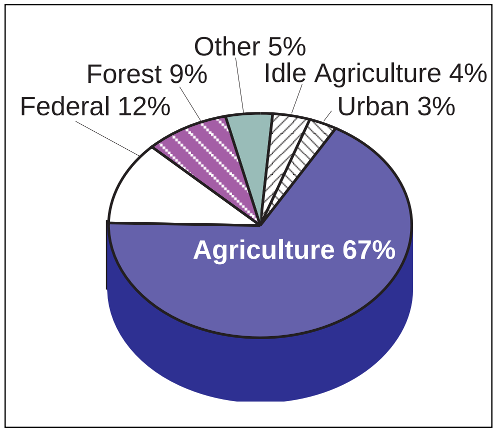

FIGURE 2. *Current land use and land cover in the upper Mississippi and Missouri river basins (Source: Bureau of Census, 1990).*

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 portion 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 just a bigger levee could have held them back. Those levees were part of the problem, 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 being 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, 1955).

These conditions were not to last for long. By the late 1600s, Europeans had begun to intervene, tinkering with nature at increasing risks 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. 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, thereby, was 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 was developed, not in a prairie but over it. As the 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 the European and 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 and 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 very quickly and hastened the water downstream. More than 8,000 drainage districts were eventually organized, draining more than 50 million acres in the Midwest alone (Lant and 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 realized. Elaborate storm sewer systems were put in place dispatching urban runoff into local streams which, unable to hold the increased flows, inevitably required dredging, straightening and, in many cases, concrete linings to move the water—and the problem—downstream.

The solution became part of the problem. This ad hoc attempt at redistribution of floodwaters from the upper to the lower watershed produced more frequent floods and floods of greater magnitude. As the yield of the deforested, agriculturalized and urbanized watershed increased by two- to threefold, 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 and 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 manmade intrusions (namely, cultivation and levees) intensified flooding; the second called for even more levees to stop the flooding. The first to be published was by Charles Ellet, Jr., an engineer who understood the hydraulics of the river and the 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 the later-to-become Chief of Engineers, Captain Andrew A. Humphreys, and Lieutenant Henry L. Abbot and endorsed levees as the only appropriate flood damage prevention technique (Arnold, 1988). This became the foundation for 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 (IDW, 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 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 proposed the restoration of selected floodplains and rivers and opposed the construction of levees, writing (IDOC, 1950):

> 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. He wrote (Sutton, 1955):

> 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 can 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, as to flood problems everywhere, is control of precipitation where it first falls. At every opportunity, the vegetative canopy 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 percent of the water-holding capacity of our soils (Brady, 1992). This capacity needs to be rebuilt. 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. Siting specific restoration projects can be facilitated by relating to 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, 1993). 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. Distributing these waters at a 3-foot depth (the approximate depth of a deep marsh), they 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).

TABLE 1. Measures of the Original and Lost Storage Capacity of the Upper Mississippi and Missouri River Basins

Year	Water Surface Area	Percent of Watershed*†
Beaver Ponds		
1600	51,100,000	11
1990	511,000	0.1
Lost	50,600,000	11
Wetlands		
1870	44,700,000	10
1980	18,900,000	4
Lost	25,800,000	6

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

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 percent of the land uses (Figure 2). Including urban development, we have actively manipulated over 80 percent of 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 measures of the original storage capacity of the basin and each offers a different perspective:

BEAVERS—Forty million beavers in

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*
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

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

1600 would have maintained 51 million acres of water surface accounting for 11 percent 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 3 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 1780s as compared to the 1980s. Based on these estimates, 45 million acres, or 10 percent of the watershed, 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 percent of the watershed. The 25 million acres of drained wetland could have provided sufficient area to store two times the floodwaters that passed St. Louis in 1993.

SOILS—It is the topsoil which 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 percent 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, 1993), accounting for almost 9 percent 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 seven percent 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 its location. Storage areas will need to be selectively sited throughout the watershed to achieve the greatest flood reduction benefits. Given that each precipitation event has its peculiar pattern or distribution, many flood scenarios will need to be considered.

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)	Percent of Upper 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 feet deep)		13.2	2.9

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

Still, there are indications that such a strategy could work. In the 1930s, 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 watershed. Although it may take more than 13 million acres, it will 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 practice 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 impacts 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. At a 3-foot depth, theoretically, this would provide a detention time of more than 18 days, or 6 days at a 1-foot depth. Treating the mean flow of the Mississippi as recorded at Thebes, Illinois, would require a modest area of close to 3 million (Table 3) acres in wetlands. If the mean 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 3-foot depth.

Numerous other benefits would accrue. This same acreage would provide significant wildlife benefits. Conservation of the organic content of topsoil has agricultural benefits: reduced erosion and increased soil moisture. Riverine wetlands located adjacent to major rivers would provide outstanding 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 arguing for 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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