Managing Ohio and Mississippi River Landscapes for the Future

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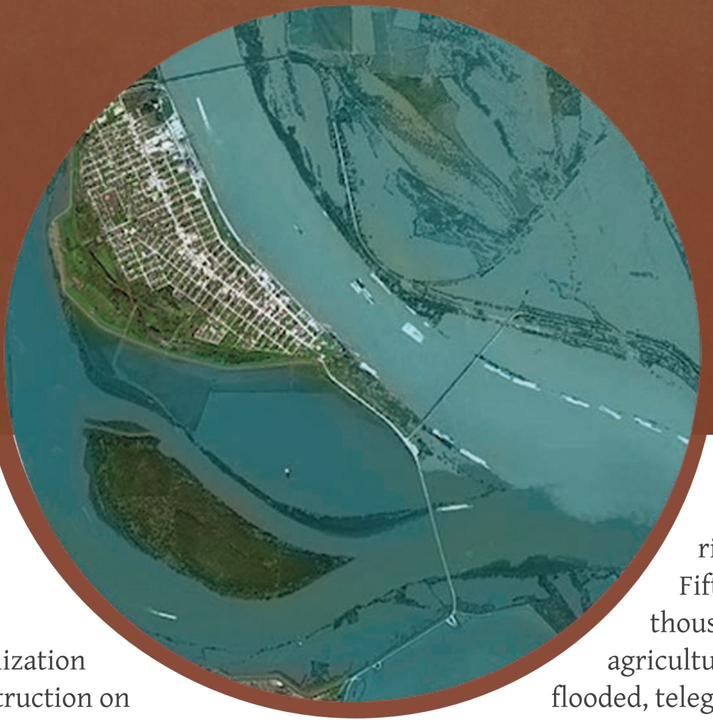
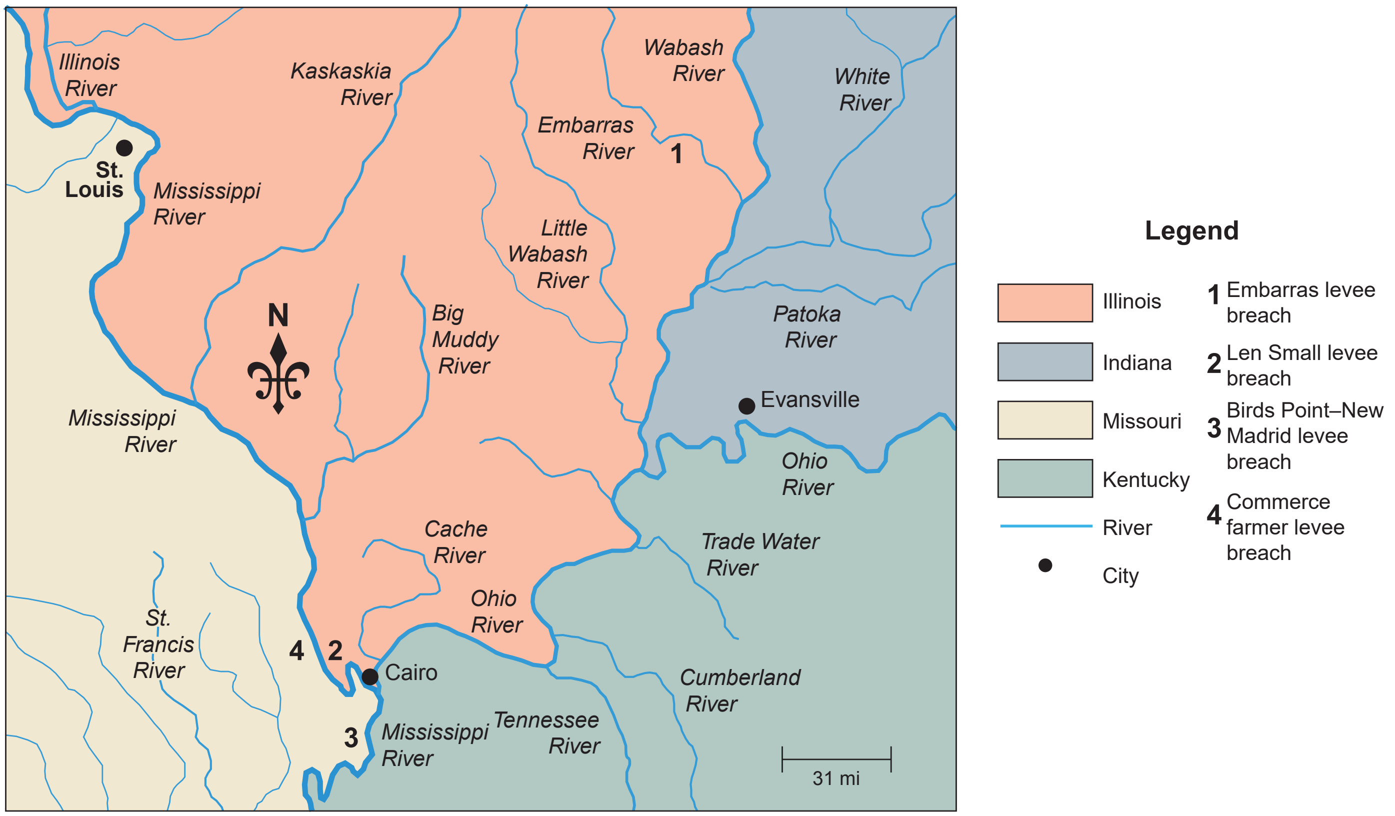


Moving water is a powerful force that humans have attempted to tame and harness since civilization began. Although levee construction on the Mississippi River occurred as early as 1717 to protect the low-lying port of New Orleans, serious river engineering to manage the river and its tributaries did not begin until 1824 [1]. The Swamp Land Acts of 1849 through 1860 accelerated private construction of levees and ditches to drain river bottomlands and manage internal and river flooding. However, it took the catastrophic flood of 1927 for the US government to fully invest in a system of levees, floodwalls, diversion ditches and dredged channels, floodways, and upland reservoirs. Management of the Ohio and Mississippi river system has evolved over the last hundred years as we have learned more about relationships among uplands, headwater streams, floodplains, and rivers. Many of the lessons were learned the hard way. Unexpected heavy winter rains in December of 1936 and a prolonged four-week January storm in 1937 over the Ohio River valley generated a 1,000-year flood from Pittsburgh, Pennsylvania, to Paducah, Kentucky, that destroyed river cities without floodwalls and severely damaged even those river cities with floodwalls. Fifty-four people died and thousands more were displaced, agricultural bottomlands were flooded, telegraph service was lost, and washed out railroad beds halted freight transportation for many months.

The completion of the Kentucky Dam on the Tennessee River after the 1937 flood increased upland water storage and improved capacity to manage floodwater downstream from the confluence of the Ohio and Tennessee rivers. In the intervening years many upland reservoirs have been built to control the volume and timing of water runoff as it flows into main stem rivers toward the Gulf of Mexico. In addition to flood control, these lock and dam reservoirs have increased dry season stream flows and made year around commercial navigation possible. Early snowmelt and prolonged heavy rainfall in early spring of 2011 over the Ohio and Mississippi river valleys created another record flood, with a river crest at the Cairo confluence (figure 25.1) that exceeded the 1937 flood. In 2011 public and private levee systems breached (map 25.1), and the US Army Corps of Engineers (USACE) activated the New Madrid Floodway. Agricultural crops were lost, and substantial



MAP 25.1 Four major levees breached on the Ohio and Mississippi rivers and their tributaries and damaged agricultural lands during the flood of 2011.

soil degradation occurred, including thick sediment deposits over fields, craters, and severe gully erosion; however, no lives were lost and there was limited property damage. Reclamation of agricultural lands, rebuilding of levees, sediment removal from road and drainage ditches, and repair of homes and agricultural structures have been costly to taxpayers and private landowners.

Despite the risks of living along the Mississippi and Ohio rivers and their tributaries, these waterways have been and continue to be sources of ecological diversity and abundance and economic prosperity fostering cultural and social centers. These rivers form the backbone transportation system for the central United States, a region rich in natural resources, fertile soils, and abundant water, making it one of the world's largest producers of corn, soybeans, and other agricultural products. The construction of lock and dam systems on the upper Mississippi and the Ohio rivers created the largest navigable inland waterway in the world, which today transports more than 60% of all US grain shipments for domestic uses and export.

This inland waterway not only has a vibrant and productive past and a vital economic present, it also has enormous potential to meet many of society's needs in the twenty-first century. Pressures to achieve global food security will only increase as world population, currently 7.3 billion, is projected to continue to grow during the next century. The agricultural productivity of central United States is key to meeting this need. Water security is one of the greatest challenges the United States and the world face now and in the coming decades. Water scarcity and quality for drinking, agricultural irrigation, industrial processes, and ecosystem services are limiting factors in assuring food security, human health, and well-being [2]. The Mississippi and Ohio river system has water in abundance, but it should not be taken for granted. The soil, vegetation, and ecosystem resources that filter and replenish these waters are at risk and must be protected to ensure quality and abundance. Climate and weather variability across the Ohio and Mississippi river landscapes affect the water cycle. The Third National Climate Assessment released in 2014 observes the modern-day landscape has experienced increases in annual precipitation and river-flow in the Midwest and Northeast over the last 50 years [3]. The 37% increase in very heavy precipitation events from 1958 to 2012 is projected to continue to increase into the future, intensifying flooding and intra-seasonal droughts. This has implications for not only flood risk and crop production but also maintenance of water depth for navigation during extreme dry periods. Further, land use and land management practices within the river system have increased rates of upland erosion and discharge of sediments [1]. These increases in sediment discharge require more frequent channel and river port dredging to maintain adequate navigation depth and port viability. In addition to increased flood risks, higher air and water temperatures and more intense precipitation and runoff are decreasing lake and river water quality with increased transport of sediments, nitrogen, and other pollutant loads.

Extreme flooding events along the Mississippi and Ohio rivers and their tributaries well illustrate the continuing challenges of public agencies (e.g., Mississippi River Commission [MRC], USACE, National Weather Service [NWS], National Oceanic and Atmospheric Administration [NOAA], and Federal Emergency Management Agency [FEMA]), river municipalities, and private levee districts to anticipate risk and manage emergency and evolving natural disasters associated with downstream flooding and increased pressure on levee-protected landscapes [4]. Of particular concern is the vulnerability of low-lying deltaic environments (river bottomlands), which are levee protected. The direct impacts of levee breaching on soil erosion, land scouring, sediment contamination, and sediment distribution, and the indirect impacts on social and economic activities, particularly agriculture, of flooded areas are extensive. We don't know when or where the next catastrophic flood event on the Ohio and Mississippi rivers will occur. The only certainty is that it will happen. So the following questions must be asked:

1. How can we be better prepared for the next flood event?
2. How can we better realize the potential of this unique inland waterway to meet navigation, ecosystem services, water supply, recreation, and other quality-of-life goals?
3. What are the adaptive management strategies needed to manage this river system for the future?

Throughout this book, we have illustrated many aspects of river systems, the up- and downstream connectivity of lands and waters, and the direct and indirect cascading effects of engineering and management in one locale spilling over into other locales. Public testimonies at MRC and USACE low and high water public hearings well reflect this connectivity when port authorities request annual dredging to remove silt and sediment deposited from upstream waters and discuss

FIGURE 25.1 The confluence of the Mississippi and Ohio rivers south of Cairo, Illinois, during the flood of 2011 was more than five miles wide and inundated bottomlands in Kentucky, Missouri, and Illinois.

the need for flood easements with adjacent districts to store and redirect floodwaters when the river reaches specific elevations at their port. Managers of upland reservoirs evaluate how much water to release by monitoring downstream navigation channels depths to ensure barges and river traffic can keep moving. Local levee districts closely watch upstream rainfall events and tributary flooding to anticipate downstream risks to their levee system. Farmers anxiously track upland rainfall as it drains into and fills local drainage ditches to determine field conditions to make planting decisions and nitrogen applications, and under worst case scenarios, when to begin sandbagging.

Managing complex river systems to ensure healthy, resilient landscapes in the near and distant future requires recognition that knowledge about these systems is incomplete. Public agencies, private organizations, landowners, and residents that live in floodplains must plan for the unexpected and be prepared to adapt when the unexpected occurs [5]. The Mississippi and Ohio river system is a huge, sprawling landscape that needs an extensive coordination and communication network of public-private partners and multiple funding sources. Many kinds of experts and local knowledge are needed to engineer and manage river watersheds to achieve resilience [5, 6]. These partnerships must be committed to continuous monitoring and assessment of the river and its landscape. They must be willing to learn from the past and able to integrate new science and technologies in managing the routine and anticipating the unexpected, adjusting and adapting as conditions and situations change. The USACE provides critical engineering services in managing and protecting river resources. Their public mission is diverse, encompassing navigation, flood risk management, river ecosystem protection and restoration, regulatory oversight, water supplies, and hydropower production. Central to accomplishing this mission is the administrative and mission-vision leadership they provide in coordinating, communicating, and creating spaces for iterative dialogues among the many stakeholders that use, manage, and value river landscapes. Local partnerships with levee districts, river port authorities, agriculture and associated enterprises, and community leaders are necessary for this mission to be accomplished.

In this concluding chapter we learn from the past and look to the future to make recommendations that we think will increase the resilience of river systems. By resilience we mean the capacity to absorb shocks and disturbances and yet retain the ecological, social, and economic structure and functionality of the system. Despite good engineering and planning efforts of humans, infrastructure system failures occur for a variety of reasons. Snow melts. Then it rains and rains. Roads and fields flood. Rivers exceed flood stage and push beyond the capacity of leveed infrastructures to keep the river out. Levees breach. Barges at high water become unmoored and damage floodgates that control water flow. Levee districts lack funds to repair and maintain their infrastructure. Citizen leaders, local organizations, and state and national agencies with different priorities and resources miscommunicate or worse don't communicate at all. Engineers, soil scientists, land use managers, port authorities, and technical support staff lack sufficient data to calculate accurately river conditions, to estimate infrastructure needs, or model out 500- or 1,000-year flood events.

Two kinds of observations and recommendations are presented: postflood assessment and management, and ongoing investments in physical and social infrastructures to improve future adaptive responses. Our list is not intended to be comprehensive but is derived from our expertise in soil science and human-social sciences. It is grounded in our knowledge of agriculture and natural resource systems and observations of leveed and unleveed landscapes; synthesized from listening to stakeholders who own and manage land in the alluvial bottomlands, levee district leaders, and upstream and downstream rural and urban stakeholders; and refined by spirited dialogues with other scientists, technical staff, leadership in public agencies and private organizations, and private landowners.

Postflood Assessment and Agricultural Lands Management

Almost 10% of the Mississippi and Ohio river watershed is alluvial bottomland and is used primarily for crop production. Between 10% (Illinois) and 30% (Missouri) of individual state crop, agricultural, and food production comes from bottomland soils. Millions of acres of agricultural floodplain lands are drained, levee-protected, and irrigated. Today, the Mississippi levee system has over 3,500 miles of public and privately managed levees from Cape Girardeau, Missouri, to New Orleans, Louisiana. Many more miles of levees are found in the Missouri River subwatershed [7] and adjacent to the upper Mississippi and Illinois rivers; the Ohio, the Tennessee, the Wabash, and the Cumberland rivers; and their tributaries. Levee breaches in 1927 flooded 27,000 square miles to a depth of 30 feet, including thousands of acres of fertile Mississippi river agricultural bottomland, and effectively ended the plantation cotton system [8].

The Flood Control Act of 1928 built more levees; made existing ones higher and stronger; and created three floodways, including the New Madrid Floodway, to divert floodwaters and reduce downstream water pressure on levees. The Flood Control Act of 1936 made flood control a federal policy and officially recognized the USACE as the major federal flood control agency. In the 1940s the Tennessee Valley Authority (TVA) built the Kentucky Dam (see chapter 19) on the Tennessee River to better control the fast rise of the Ohio River during spring rains and slow its rush to the Cairo confluence. Despite public and private investments and extensive engineering efforts, once-in-a-lifetime flood events in 1945, 1975, 1993, 1997, 2008, and 2011 on the upper Mississippi, Missouri, and Ohio rivers continued to result in flooding, levee damage, destruction of property, and devastation of soil resources. These floods led to record erosion levels on both bottomland and upland soils. Further, natural and induced levee breaches on Ohio and Mississippi rivers resulted in short- and long-term soil contamination and agricultural crop damages.

Addressing Soil Erosion and Degradation

Soil erosion caused by these floods brings into question the adequacy of current soil conservation practices and their implementation (or not) by landowners. Soil conservation for the most part is a social learning process whereby experience from past events informs changes in practices to prevent resource degradation during future events. The floods of 1993 and 1997 provided excellent opportunities for Midwest conservationists to improve upon conservation practices in preparation for future events, such as the 2008 flooding in the Mississippi and Missouri river basins. The impact on alluvial soils in these river basins was partially addressed by raising and strengthening some of the levees (see chapters 11, 12, and 17). In other areas the land use was converted from agricultural use to a conservation use. However, on the upland Midwest soils the flooding lessons were not learned. If conservationists and landowners had learned from the past, the 2008 and 2011 floods would not have had as much land scouring and soil erosion-related destruction as we see on both the upland and bottomland soils.

The question remains: what have we learned from the 1993, 2008, and 2011 floods, and will we implement practices to protect against future floods? These floods in the upper Mississippi river basin caused considerable devastation with extensive property loss. The estimates of financial loss because of structural damages can be readily assessed when each property has a known market value. However, we do not have this kind of cost analysis or market value data for the soil and water degradation damage. Further, even if the data existed, the eroded soil cannot be easily replaced. Thus, we need a plan and commitment to save our soil.

Conservationists and soil scientists have not recommended changing the current tolerable soil loss (T) values for soils (as high as 5 tons per acre) on the uplands and bottomlands of the Midwest. The T values are set based on how fast topsoil and subsoil are formed in specific parent materials. The problem is two-fold. The acceptable T value loss metrics are likely set too high. And second, cultivated soils are subject to more intense rainfall events before and during planting when soils are not protected by vegetation. As a result greater soil erosion, water runoff, and sedimentation occur than our equations would predict. Perhaps one starting point is to assume a more intense rainfall factor (based on different weather and climate scenarios) than currently used to calculate soil loss (for the Universal Soil Loss Equation [USLE], the Revised Universal Soil Loss Equation 2 [RUSLE 2], and the Water Erosion Prediction Project [WEPP]). A 2013 study of an upstream Iowa agricultural landscape with intense row crop cultivation suggests that land use changes could reduce flood events, decreasing both the number and frequency of severe flooding [9]. Several scenarios were modeled, and the greatest flood risk reduction was found to be associated with conversion of all cropland to perennial vegetation. While this is not practical from an economic nor food security point of view, a second scenario of converting half of the land to perennial vegetation or extended rotations could have major effects on reducing downstream flooding and reducing soil erosion.

This serves as more evidence of the importance of increasing infiltration and reducing soil loss from tillage, erosion, and water runoff when soils on the uplands are used for row crops. While many soil and water conservation management and cropping practices (such as terraces, grassed waterways, strip cropping, fewer row crops in the rotation, and conservation tillage including no-till) reduce soil erosion when utilized, there is a need to expand the use of filter strips; utilize cover crops on sloping and eroding soils; increase the use of conservation tillage; add small grains and forages into the crop rotations; construct more temporary water storage dams, check dams, or retention ponds on the uplands; and take highly eroded lands out of row crop production and replace with perennial forages or timber (see chapter 9). If more runoff water and sediment can be retained on the uplands for a longer period of time, infiltration will increase, and crop production losses will be reduced, resulting in less degradation of the bottomland soils and less sediment in the surface waters.

It is also critical to assess the impacts of flooding on agricultural lands post–levee breaching to guide adaptations that prepare for future flood risks. Assessment of land scouring and deposition effects on soil productivity and long-term agricultural production is key to understanding the impacts of flooding on soils and profitability of future crops. Levees protect public and private lands from the consequences of periodic flooding. However, when they fail naturally or as a result of human induced breaching, the consequences are disastrous and can take different forms. The damages include crop loss; levee damage; crater lakes; gullies; thick sand deltaic deposits; scoured land; irrigation equipment destruction; soil and water degradation; building structure and farmstead damage; blockage of drainage and road ditches; road deterioration; and ecological damage to forests, parklands, and wetlands. The effects of levee breaches and flooding on soils and soil productivity are seldom determined since updated soil surveys are not routinely made in response to levee breaching and flooding. In the case of the O'Bryan Ridge gully field (see chapter 13) following the opening of the New Madrid Floodway, the damage to soils after restoration attempts included the permanent loss of 30% of the agricultural productive capacity as result of land use conversion, land scouring, water erosion, and gully field formation with little deposition of sediments since the rushing floodwaters drained quickly and transported the sediments from the field.

Resurvey and Assess Soil Conditions

There is a need to resurvey and assess soil conditions following natural and human induced levee breaches to (*a*) improve characterization and measurement of eroded soils and distribution of sediment contaminants after breaching, (*b*) assess contamination effects on soil productivity and long-term agricultural production, and (*c*) reassess current levee location and design in response to expected future increase in extreme weather patterns (flooding and drought) and changing climate conditions. Better data and assessment of soil conditions postflooding can provide valuable guidance in the restoration of craters, gullies, land scoured areas, and contaminated sediment depositional sites and thereby improve remedial effectiveness, future risk analysis, and levee management decision making. This information can increase the capacity of public and private levee districts to evaluate and restore sediment contamination sites created after a levee is breached and increase the resilience of the agricultural landscape to manage future high water and flood events. Reiterating our recommendation from chapter 24, an agreement between the USACE, MRC, and the USDA Natural Resource Conservation Service to conduct a land scouring and deposition surveys after every levee breach and to update the soil survey maps would ensure more effective responses.

A pattern of intensive resource use—human, equipment, energy, financial, and social—emerges from levee breach events and reconstruction investments. These encompass levee repair, return of land to productivity, and creation of a landscape that is less vulnerable to future flooding and levee breaching stress. Resilience analysis utilizes continuous monitoring and assessment but assumes that there will always be unidentified or emergent factors that cannot be accounted for. Expectations of the unpredictable lead to the development of more flexible engineering and management that better respond to uncertainty and "surprise" conditions. Engineers, soil scientists, farmers, agricultural production specialists, and rural community leaders in levee-protected regions should consider alternative designs that incorporate natural wetlands and bottomlands into the levee system to increase capacity to deal with the unpredictable. Designs that integrate natural wetlands can reduce water pressure on levee systems; increase water storage capacity; absorb and transform excess nutrients that degrade water quality; reduce social, biophysical, and economic impacts of soil degradation and contamination; and improve the overall resilience of agricultural productivity in deltaic environments [9, 10, 11, 12, 13].

Maintenance and Modernization Investments in Physical and Social Infrastructure

The full potential of the Mississippi and Ohio river system has not yet been realized. While it has a glorious and colorful past, the nation and its leadership have not yet captured and reproduced a compelling vision for the future of this unique inland waterway. A unified vision and purposeful investments in physical and social infrastructures are necessary to create a world-class river system that achieves the multifunctional goals of a national economic engine that relies on and protects ecological resources and is a source of technological, social, and cultural vibrancy. Currently, it has pockets of prosperity and poverty; cities, ports, and levee districts that compete for scarce federal dollars; and fragmented priorities and investments that benefit some locales and disadvantage others.

We first observe that this inland waterway is a complex human-natural system, which is geographically distributed, subject to high levels of local variability, and yet a unified whole. Three areas of action are proposed to prepare, guide, and adapt this amazing resource for the future. The first is the physical infrastructure. There is an urgent need to operate and maintain navigation as an inland system and invest in repair and modernization of aging lock and dam structures. Much like the national highway system, this inland river system, encompassing more than 40% of the United States, needs substantive systematic infrastructure investments. Failure and closure of one lock and dam because routine maintenance and repairs have not been kept up to date harms the entire system. Silting in of one port along the river removes a node in the transportation system that affects river traffic and reverberates throughout the economies of that port and the whole system. Second, managing complex systems requires data about individual as well as integrated components of the entire system in order to monitor, evaluate conditions, and adaptively manage. Standardized metrics are essential to a system approach of management. Data must be spatially comparable across the system, able to be aggregated, and accurately modeled when primary data are not easily assessable. These scientific data must be readily available and accessible to the many local, regional, and national partners that evaluate technologies and best practices, and make a myriad of daily decisions associated with river management. Last, the river system is deeply intertwined with human and social systems. Human perspectives and goals, social relationships, and actions are key factors that reflect how the river system is valued and cared for as well as influence how it is managed.

Inland Navigation System

Prior to the 1820s, periods of drought often affected river navigation on the Ohio (see chapter 18), Tennessee (see chapter 19), Cumberland (see chapter 20), Upper Mississippi (see chapters 21 and 22), and Illinois (see chapter 23) rivers. When Lewis and Clark headed down the Ohio River in 1803, there were no locks and dams. In dry years the water depth was very low, and navigation was often delayed until high water. The major physical hurdle on the Ohio River was the Falls of the Ohio River near Louisville, Kentucky, which steamboats could only pass over when the river was high. The USACE, in 1825, began building locks and dams on rivers to permit year-round navigation and shipping. Today we have a lock and dam system that assures a nine-foot navigation depth for the entire length of the Ohio River and the upper Mississippi from Cairo, Illinois, to Minneapolis, Minnesota. After the construction of the Kentucky (1940s) and Barkley (1960s) reservoirs, it was possible to release sufficient water for weeks or even months to maintain an additional four feet of water in the lower portion of the Ohio River. These early wicket dams and lock chambers have been systematically replaced (see figures 18.4 and 18.5). The Olmsted Lock and Dam on the Ohio River just north of the Cairo confluence is slated for completion in 2020. This modern, state-of-the-art infrastructure (see figures 18.2 and 18.9) is being built at a cost of $3 billion and replaces these last two aging wicket dams and locks on the Ohio River. However, many locks and dams throughout the upper Mississippi River and Illinois River systems are aging, with resources limited for even routine maintenance and repairs. These systems also need to be modernized.

Locks and dams on the upper Mississippi and Ohio rivers and their tributaries increased the volume and weight capacities of barge and river traffic and boosted the economies of river cities. Many river ports are at the intersection of rail lines making the port city a transportation hub for agriculture, mining, and other commodities for domestic use and export. The current and future viability of these river ports and harbors throughout the system is dependent on retaining and increasing commerce through active routine maintenance and modernization of the navigation system. America's Watershed Initiative Report Card for the Mississippi River [14], published in 2015, gives the Mississippi River infrastructure maintenance a D+. The USACE operation and management budget covers only routine maintenance and consistently underestimates the amount needed to keep inland navigation infrastructure operating. Deferred maintenance and repairs are increasing and increase the risk of unscheduled delays. High water events deposit silt and sediment loads in these ports and over time can reduce a 25-foot harbor to 8 or 9 feet, limiting the tonnage barges can carry. Small ports and harbors often need to be dredged annually, especially after multiple high water events. However, they currently lack a dependable strategy for funding dredging operations, which require annual congressional appropriations. Not only must local leadership continue to lead the way in maintaining and modernizing their own port, they must also build and strengthen partnerships with other ports up and downstream. Cooperative agreements, knowledge exchanges, resource sharing, and a cohesive vision for the Mississippi and Ohio rivers as an inland waterway with global reach can bring visibility and additional investments to the system.

Increased Science and Data Availability for Improved Decision Making

Scientists track the frequency, duration, magnitude, timing, and rate of change of water, material, and biotic fluxes to downstream waters [15] to measure the degree of connectivity of land and water within a watershed. These factors have cumulative effects across the entire watershed and influence the variety of functions that rivers and their floodplains provide. Streams, wetlands, and rivers can serve a number of functions simultaneously and affect the structure and function of downstream waters [15]. These functions include (*a*) export of downstream water, soil, nutrients, and organisms; (*b*) removal and storage of sediment, contaminants, and water; (*c*) provision of habitat for organisms; (*d*) transformation of nutrients and chemical contaminants into different physical or chemical forms that make them less harmful; and (*e*) regulation and delay of the release of floodwater, sediment, and concentrated contaminants.

The structure and shape of rivers and floodplains and their relationship with each other is always changing and continually evolving with changes in land use, climate, and human activities. Mainline levees block river flooding. Interior drainage ditches and large pumps drain surface and groundwater seepage to protect agricultural and urban land uses. Floodplain lakes and backwaters are scoured during high flows and accumulate fine grain sediments during low water periods. Navigation pools behind locks and dams have changed sedimentation and shoreline erosion processes. Clearing the river of woody debris, construction of channel training structures such as chevrons and wing dams, dredging, and redistribution of dredged material are modifications that have changed the geometry of river channels and floodplains [1]. These modifications have stabilized the main channel, reduced the width, and deepened the river as intended. Dams have increased water levels, slowed current velocities, and flooded low-lying floodplains within the navigation pool [1].

Over time, wind-driven and boat-generated waves in impounded areas of navigation pools have eroded shorelines resuspending and redistributing sediments. Sedimentation is among the most critical problems in the river and a major concern to natural resource managers (ecological impacts), river port authorities (dredging is costly), and the USACE (maintaining the navigation channel). The USACE analyzes data on channel geometry, river contours, sediment delivery to the river, hydrologic records, and river engineering structures to track changes and evaluate their cumulative effects. However, the capacity to forecast accurately changes in the geometry of river channels and floodplains is limited by insufficient past and current condition data. Data such as floodplain topography; sediment delivery rates from tributaries; and quantitative measures of geomorphic responses to impoundment, river regulation, and channelization are dynamic and continually in flux and need documentation [1].

Data limitations are also a challenge in preparing river and flood forecasts. Two types of data are fundamental for the NWS to issue river forecasts and flood warnings [16] necessary for the USACE, levee districts, and landowners to prepare for potential flood conditions. The first is the river stage or the water depth, usually measured in feet. The second is the total volume of water that flows past a point on the river for some period of time (flow or discharge), measured in cubic feet per second or gallons per minute. River stage and river discharge are measured at a specific location on the river called a stream-gaging station. The US Geological Survey (USGS) operates and maintains a network of 7,292 stations throughout the United States, almost 4,000 of which are used to forecast river depth and flow conditions [16]. Most of these gaging stations are automated with sensors that continuously monitor and report river stages to one-eighth of an inch. Battery-powered stage recorders with satellite radios transmit data to USGS and NWS computers even when high waters and strong winds disrupt normal communication systems. This is essential, especially at remote sites, for tracking how quickly water is rising or falling. River discharge is usually estimated from preestablished rating curves that represent the relationship between river stage and discharge. USGS field personnel periodically measure river discharge in person to detect and track changes in discharge and assure the rating curves reflect real-time conditions as accurately as possible. Flood conditions can effect scouring and deposition of sediment as well as in-stream bed and bank roughness. These in turn can change the river stage and discharge relationship resulting in the need to develop a new stage/discharge rating.

Flood stage metrics are based on the impact to people in a specific location, that is, the water level at which the river threatens lives, property, or navigation. Flood stage on the river gage is commonly measured at the level of the water surface above an established zero point at a given location. The zero references a point within 10 feet of the bottom of the channel, which is also usually the mean sea level. Flood stage is only calculated for bodies of water that affect communities. For example, the Cairo gage at flood stage is 40 feet in the Ohio River channel with a sea level elevation of 310 feet. The peak 2011 flood levels measured 62 feet on the Cairo river gage (a sea level elevation of 332 feet), or 22 feet above flood stage. There are five levels of flooding which are used to communicate flood risk and potential impacts to human settlements [17]. The first is an "action stage" where the water surface is near or slightly above its banks with water overflowing into parkland or wetlands but not human-made structures. "Minor flood stage" is slightly above flood stage with minor flooding of low-lying farmland or roads. "Moderate flood stage" begins to inundate buildings, close roads where low-lying areas are cut off, and cause some evacuations. "Major flood stage" is significant, life-threatening flooding with low-lying areas completely covered, buildings submerged, and large-scale evacuations [18]. A "record flood stage" is the highest level that a river has reached since flood measurements were historically recorded on that particular river gage. However, a record flood does not necessarily have to be a major flood, but is simply the highest level ever recorded on that community's river gage.

It should be readily apparent to the reader that river gage measurements and definitions of major and minor flood stages at Cairo, Illinois, are quite different numbers with different meanings than those at Paducah, Kentucky; Keokuk, Iowa; or Cincinnati, Ohio. River gage data are location-specific. Local residents know what the numbers on their gage mean in relationship to potential for flood damage to crops and local infrastructure, and the need to evacuate. River gages are not a standardized metric that can be used to monitor and assess changes in the river system. Inconsistencies in river stage data make local decision making difficult. Decisions are made based on river stage forecast. Historic river stages are used as analogs for when water will cover certain local roads; whether to sandbag around homes and buildings; whether to evacuate; and the urgency, timing, and speed to take action. Further complicating system-wide monitoring and assessment is the fact that current river elevation data are not reported in the same way for dam or project structure elevations. There is a need to standardize reference river system metrics using sea level elevations so they have system-wide meaning. Locals already know the interpretation and meaning of readings on their own gage but often do not know the implications of upriver or downriver gage readings. This hampers downriver decision making as leaders track upstream conditions in order to make timely, appropriate decisions.

Related to this issue are data metrics and limitations noted by levee districts and their engineers who need to make flood easements and agreements up- and downriver with other districts. These agreements are needed to redirect floodwater and make floodwater storage arrangements. When agreements are not in place regarding when to accept water from another district at a specified elevation, sequencing of the pools and storage as river elevations change is quite difficult. There is a need for standardization of river level metrics and a lot more data on tributaries and calculations for storing and holding upland water in order to manage main stem river elevations. This will help set appropriate elevations based on engineering science and local knowledge as triggers for activating agreements. Currently local gages and flood records used as the baseline for measuring changes in the river height do not translate well across the system. This makes it difficult to maintain infrastructure and adapt to changing conditions when science-based changes in the river profile are not up to date or easily compared across the system.

Human Perspectives, Social Relationships, and Actions

It is well recognized that managing river landscapes involves a great deal of engineering as well as the physical and natural sciences [19]. Often overlooked is the human factor—the patterns of civilization, the human and social decisions and actions that underlie the remaking of the natural environment to reflect human values and aspirations [6, 20]. The Mississippi and Ohio river system is a multiple-use resource shared by many. This "public commons" presents huge issues of how to manage to meet complementary and competing goals within resource constraints. The USACE is charged by Congress to engineer this resource to ensure navigation, mitigate flood risk, protect the river ecosystem, and provide regulatory oversight. However, engineering science is silent on how to select project locations and chose from a variety of possible designs to select those most socially acceptable. Further, legislation, policies, regulations, and planning documents do not provide adequate guidance for prioritizing projects, evaluating engineering designs, or assuring local or regional support for engineered projects.

People have diverse and conflicting beliefs, attitudes, and opinions about the value of the river system and how it should be managed. The uses of this resource involve public and private lands, agricultural practices and policies, natural resource rights, public water supplies and disposal, flood risk perceptions and expectations, lifestyle and consumption of nature behaviors, and allocations of moral and financial responsibilities [6]. Individual and local self-interests often compete for "winning" their preferred project and resources to construct it. These self-interests lead to fragmented solutions with unintended downstream or upstream consequences. Self-interests can also polarize cross-sectoral interests and block capacity to manage the river as a whole system. For this river system to become a world-class system, the people of the region need to view it as a shared, public commons worthy of investing time, energy, and financial resources that are of benefit to the whole region. They must have a vision of it as a unique inland waterway and develop a shared normative understanding about its economic, social, and ecological importance. They must be willing to place the public good over personal self-interest and accept the rights and obligations of living, working, and owning land in this region.

How is a shared vision constructed? How do we create communities of cooperation that don't ignore or belittle the diverse self-interests and sector-specific economic, environmental, or social concerns but listen and learn from each other in order to find shared solutions to common problems? Social science [6, 20, 21] suggests four key elements are foundational to constructing a civic structure capable of realizing system level goals: (*a*) a common vision; (*b*) iterative exchanges of knowledge and perspectives; (*c*) public and private collaborative partnerships in the public interest; and (*d*) processes and mechanisms that integrate and utilize scientific and nonscientific knowledge in priority setting and mobilization of resources to accomplish the shared vision.

The USACE is well positioned to provide the mission-vision leadership and develop mechanisms and processes for integration of scientific and nonscientific knowledge. River management requires communication, cooperation, coordination, and joint investments across many federal and state public agencies (e.g., FEMA, NOAA, US Environmental Protection Agency, and USDA NRCS), local municipalities, levee and soil and water districts, private organizations, and individual landowners and managers. Thus, as a public agency they cannot single-handedly develop the vision nor carry it alone. However, the federally mandated annual high and low water public hearings conducted by the USACE and MRC are critical forums that provide neutral space for public dialogue, learning, and listening exchanges on river issues. These iterative exchanges of knowledge and perspectives among landowners and managers, stakeholders, public agencies, not-for-profit organizations, citizen leaders, and taxpayers provide opportunities for the construction of shared concerns and initiation of collaborative efforts to find and implement solutions in the public interest. The USACE creates a respectful and orderly process for listening and information exchange. They use the public hearing forum to convey that citizen voices are heard and are part of the public record. These hearings enable public exchanges that communicate engineering challenges and progress. They are a place where sectoral organizations and individuals can publicly voice frustrations and concerns, recommend resource allocations, suggest technologies, and bring scientific knowledge to problem identification and potential solutions. Equally importantly, these hearings are opportunities for stakeholders to express gratitude for and acknowledge the value of public and private projects that have met community's needs.

Effective management that reflects citizen public interests depends on building cross-sectoral and geographically diverse partnerships. There are abundant examples of public and private co-joint partnerships throughout the river system. Leadership for these partnerships has developed historically and continues to emerge along the entire spatial and temporal scale, including levee districts and local port authorities. The Sny Island Levee and Drainage District in Illinois (see chapter 4) and Little River Drainage District in Missouri (see chapters 5 and 6) are examples of such partnerships. Collaborative partnerships are built from social relationships and sectoral networks of trust and mutual respect that share common goals. For the inland waterway vision and profile to be raised to a national level, these effective local partnerships need to extend their geographic and sectoral relationships to encompass a larger network. Another effort, the America's Watershed Initiative (http://americaswatershed.org/), a public-private-sector collaborative has begun working to find solutions to the challenges of managing the Mississippi River [14]. Their steering committee represents a diversity of sectors including conservation, navigation, agriculture, flood control and risk reduction, industry, academic, basin associations, local and state government, and the USACE/MRC.

These partnerships foster the passion and energy necessary to continually reinforce the shared vision of a world-class inland waterway and public norms of civic cooperation. Lastly, public agencies and public-private partnerships have a variety of processes and mechanisms they can use to bring scientific information to bear on management decisions. They also have roles that help ensure that scientific and nonscientific knowledge are integrated into priority setting, decision making, and mobilization of resources. These processes include formal and informal public gatherings ranging from in-person and virtual meetings; uses of print and visual media, websites, chat rooms, and Twitter; river festivals; and community and river-wide celebrations. Regular established and ad hoc workgroup meetings around specific action items, sectoral and civic organizational meetings, and cross-geographic groups all have potential to communicate and reaffirm a region-wide vision and provide opportunities for groups, agencies, and individuals to act on that vision.

Final Observation

Much can be learned by observing and studying the human and natural systems of river landscapes. We framed this book as a series of short case studies about leveed agricultural lands, river navigation, upland reservoirs, and landscape management for flood risks. Together these stories reveal that change is the only certainty in river systems. Many factors influence and affect change. The connectivity between soil and water creates vulnerability and opportunity. People differ greatly in their vision for and functional uses of river landscapes. Managing for resilience can best prepare us to adapt to future unknown risks and catastrophes.

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[1] Theiling, C. 1999. River geomorphology and floodplain habitats. *In* Ecological Status and Trends of the Upper Mississippi River System 1998: A report of the Long Term Resource Monitoring Program. April 1999. LTRMP 99-T001. La Crosse, WI: US Geological Survey, Upper Midwest Environmental Sciences Center.

[2] Morton, L.W. 2014. Achieving water security in agriculture: The human factor. Greening the Agricultural Water System. Agronomy Journal 106:1-4, doi:10.2134/agronj14.0039.

[3] Melillo, J.M., T.C. Richmond, and G.W. Yohe (eds). 2014. Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment. US Global Change Research Program. Washington DC: US Government Printing Office.

[4] Camillo, C.A. 2015. Protecting the Alluvial Empire: The Mississippi River and Tributaries Project. Vicksburg, MS: Mississippi River Commission.

[5] Park, J., T.P. Seager, P.S.C. Rao, M. Convertino, and I. Linkov. 2013 Integrating risk and resilience approaches to catastrophe management in engineering systems. Risk Analysis 33(3):356-367, doi:10.1111/j.1539-6924.2012.01885.x.

[6] Morton, L.W., and S. Brown. 2011. Pathways for Getting to Better Water Quality: The Citizen Effect. New York: Springer Science and Business.

[7] Gellman, E.S., and J. Roll. 2011. The Gospel of the Working Class. Urbana-Champaign, IL: University of Illinois Press.

[8] Barry, J.M. 1997. Rising Tide: The Great Mississippi Flood of 1927 and How It Changed America. New York: Simon and Schuster.

[9] Schilling, K.E., P.W. Gassman, C.L. Kling, T. Campbell, J.K. Jha, C.F. Wolter, and J.G. Arnold. 2013. The potential for agricultural land use change to reduce flood risk in a large watershed. Hydrological Processes, doi:10.1002/hyp.9865.

[10] Weber, W.L. 2015. On the economic value of wetlands in the St John's Bayou-New Madrid Floodway. Cape Girardeau, MO: Southeast Missouri State University, Department of Economics and Finance.

[11] Polasky, S.T., K. Johnson, B. Keeler, K. Kovacs, E. Nelson, D. Pennington, A.J. Plantinga, and J. Withey. 2012. Are investments to promote biodiversity conservation and ecosystem services aligned? Oxford Review of Economic Policy 28(1):139-163.

[12] Jenkins, W.A., B.C. Murray, R.A. Kramer, and S.P. Faulkner. 2010. Valuing ecosystem services from wetlands restoration in the Mississippi Alluvial Valley. Ecological Economics 69:1051-1061.

[13] Kozak, J., C. Lant, S. Shaikh, G. Wang. 2011. The geography of ecosystem service value: The case of the Des Plaines and Cache River wetlands. Illinois Applied Geography 31:303-311.

[14] America's Watershed Initiative. 2015. Methods report on data sources, calculations, additional discussion, America's Watershed Initiative Report Card for the Mississippi River. October 9. http://americaswater.wpengine.com/wp-content/uploads/2015/10/Mississippi-River-Report-Card-Methods-v10.1.pdf.

[15] US Environmental Protection Agency. 2015 Connectivity of streams and wetlands to downstream waters: A review and synthesis of the scientific evidence. EPA/600/R-14/475F. Washington, DC: Office of Research and Development US Environmental Protection Agency.

[16] Mason, R.R., and B.A. Weiger. Stream gaging and flood forecasting. US Geological Service. http://water.usgs.gov/wid/FS_209-95/mason-weiger.html.

[17] National Weather Service. Glossary. Flood stage; zero datum; mean sea level. http://w1.weather.gov/glossary/.

[18] Lowery, B., C. Cox, D. Lemke, P. Nowak, K.R. Olson, and J. Strock. 2009. The 2008 Midwest flooding impact on soil erosion and water quality: Implications for soil erosion control practices. Journal of Soil and Water Conservation 64(6):166A, doi:10.2489/jswc.64.6.166A.

[19] Camillo, C.A. 2012. Divine Providence; The 2011 flood in the Mississippi River and tributaries project. April 5. Protecting the Alluvial Empire: The Mississippi River and Tributaries Project. Vicksburg, MS: Mississippi River Commission.

[20] Morton, L.W. 2008. The role of civic structure in achieving performance-based watershed management. Society and Natural Resources 21(9):751-766.

[21] Morton, L.W., Y.C. Chen, and R. Morse. 2008. Small town civic structure and intergovernment collaboration for public services. City and Community 7(1):45-60.