

# Middle Mississippi River: A Critical Transportation, Flooding and Ecological Corridor Needs Mitigation and Restoration

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## Abstract

The Middle Mississippi River extends south from the confluence of the Missouri and Mississippi Rivers at St. Louis, Missouri to the confluence of the Ohio and Mississippi Rivers at Cairo, Illinois. The length of the Middle Mississippi River is 310 km and the river falls 67 m or at the rate of 23 cm/km. Most of the shipping traffic from the Upper Mississippi, Illinois, and Missouri Rivers passes through this Middle Mississippi River corridor where it merges with the Ohio, Tennessee, and Cumberland River shipping traffic and continues down the Lower Mississippi River to the Gulf of America (formerly the Gulf of Mexico). The primary objectives of the paper are to document how geological and landscape resources of the Middle Mississippi River have contributed to the successful water resource and economic development of a historically rich region in North America and to identify the anthropic, environmental, and natural resource risks to the Middle Mississippi River basin. Historically, the Middle Mississippi is prone to flooding. A series of levees has been created to protect both urban and agricultural areas. In addition, the New Madrid floodway was created by the United States Corps of Engineers (USACE) to protect both urban and agricultural areas in 1930s to reduce the flooding at the confluence of the Ohio and Middle Mississippi rivers and the Lower Mississippi River. The Middle Mississippi River section is characterized by its diverse habitats, including floodplain forests, wetlands, and islands, which are crucial for various wildlife species. The Middle Mississippi River National Wildlife Refuge, established in 2000, plays a significant role in protecting these habitats and providing a sanctuary for migratory birds and resident wildlife. The Middle Mississippi River is a vital ecological and historical corridor, known for its rich biodiversity, recreational opportunities, and conservation efforts. American Rivers named the Middle Mississippi River among

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*America's Most Endangered Rivers* of 2014, shining a national spotlight on the impact a rebuilt levee at the New Madrid Floodway poses to wildlife habitat.

## Keywords

Middle Mississippi River, US Army Corps of Engineers, Confluence, Ohio River, Missouri River, Levees, Mississippi River Commission

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## 1. Introduction

Olson and Morton [1] noted “In 1879, Congress created the Mississippi River Commission (MRC) to replace the State Board of Levee Commissioners. Still serving today, the MRC has a seven-member governing body. Three of the officers are from the USACE, including the chairman who is the final decision maker when it comes to opening the floodways. Another member is an admiral from the National Oceanic and Atmospheric Administration. The other three members are civilians, and at least two of the civilian members are civil engineers. Each member is appointed by the president of the United States. Senate confirmation of the selection is no longer necessary. The MRC is the lead federal agency responsible for addressing the improvement, maintenance, and control of the Mississippi River (Figure 1). The MRC and USACE sought to deepen the Middle Mississippi River and make it more navigable and less likely to flood. In 1885, the USACE adopted a ‘levees-only’ policy (Figure 2). For the next 40 years, the USACE extended the levee system, sealing many of the river’s natural outlets, including the ones near New Madrid and Cape Girardeau, Missouri, along the way.”

“The Middle Mississippi River has been managed since the 1800s by the USACE in partnerships with the MRC, and states with levee and drainage districts. Much of their efforts have been to reduce the effects of flooding on agricultural bottomlands and river cities and to create shipping channels that can function in droughts. Since the 1970s, the USACE river managers have invested in infrastructure maintenance and replacement. River siltation is an annual problem, and ongoing dredging is required to keep port city harbors open and assure navigation depths. A variable and changing climate continues to create natural and human catastrophes as evidenced by the 2011 record flood at the confluence of the Middle Mississippi and Ohio rivers. This record flood, reaching 18.8 meters on the Cairo, Illinois, river gage (Figure 3), was followed by a near-record drought in 2012 that reduced the Ohio River depth to 2.5 m above the 3 m deep shipping channel, resulting in only 5.5 m of water for deep draft barges. Dredging to maintain the shipping channel on the Middle Mississippi River near Thebes, Illinois, during the 2012 drought was extremely difficult because of the narrow, bedrock-lined navigation channel, a remnant of an ancient upland bridge [1].”

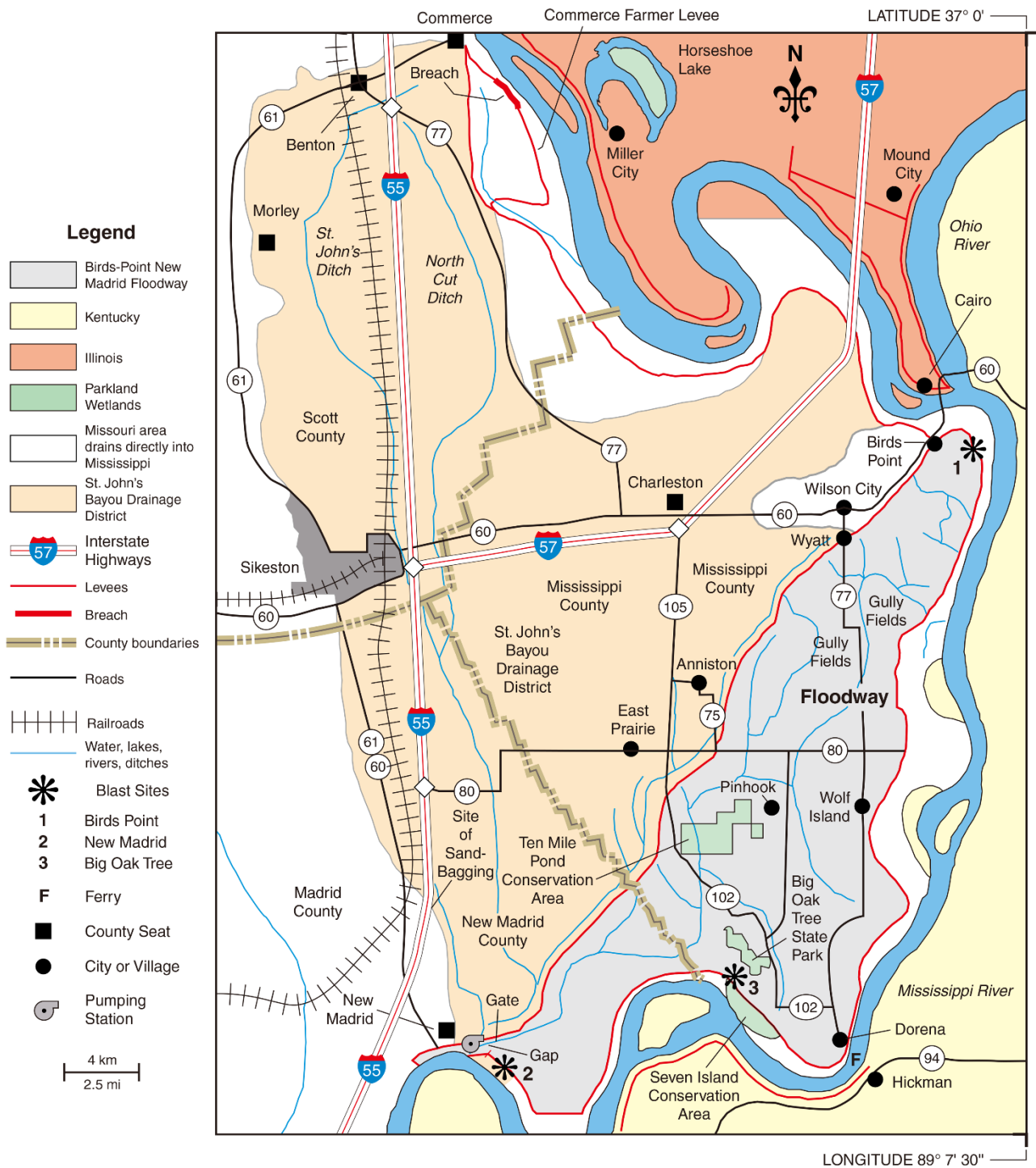
In recent years, the USACE has conducted extensive research on wetlands and river ecosystems to better understand the river-land relationship. They have restored,



**Figure 1.** Six major sub-watersheds make up the Mississippi River basin. Map by Mic Greenberg. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

created, and enhanced tens of thousands of hectares of wetlands yearly to increase floodplain storage capacities during high water and protect the biodiversity of the natural river ecosystem. As we enter the twenty-first century, three major societal concerns have emerged: a changing climate; food insecurity; and homeland security associated with infrastructure, navigation, and water quality and supply. All three themes run throughout this paper. Each section is a case study from which much can be learned to better plan. These short documentaries focus on the Middle Mississippi River, how its confluence with Missouri River creates something far greater than the sum of their flows, and the bottomlands that are sources of wealth and risk to those whose lives are intertwined with the river. They illustrate levee-protected agriculture and breach management when the river exceeds flood stage (**Figure 4**); dredging in drought to assure a navigable channel; and

locks, dams, aqueducts, and reservoirs engineered to tame the great river and its tributaries for human uses. Collectively, these case studies portray the multifunctional value of the rivers and human attempts to manage rivers and their bottomlands



**Figure 2.** St. Johns Bayou Drainage District and the New Madrid Floodway in Missouri and their systems of levees protect agricultural lands from Mississippi River flooding but have altered the natural internal drainage of both basins. Map by Mic Greenberg. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 3.** The Cairo, Illinois, river gage on the Ohio River is used to determine river height and when it is necessary to open the Birds Point–New Madrid Floodway to relieve downstream river pressure. Photo Credit: Lois Wright Morton. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 4.** During the spring of 2011, barges were anchored on the Mississippi riverbank next to the flooded Fort Defiance State Park. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

that are sources of wealth and risk to those whose lives are intertwined with the rivers. They illustrate levee-protected agriculture and breach management when the river exceeds flood stage (**Figure 5**); dredging in drought to assure a navigable channel; and locks, dams, aqueducts (**Figure 6**), and reservoirs engineered to



**Figure 5.** Agricultural fields are covered by deltaic sand deposits, water, and trees moved and deposited by rushing water through a levee break on the Embarrass River, Illinois, in June of 2008. Photo credit: Ken Flexter, Jasper County Natural Resources Conservation Service Field Office, Newton, Illinois. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 6.** The Sny River aqueduct passes under the Kiser Creek Diversion channel. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

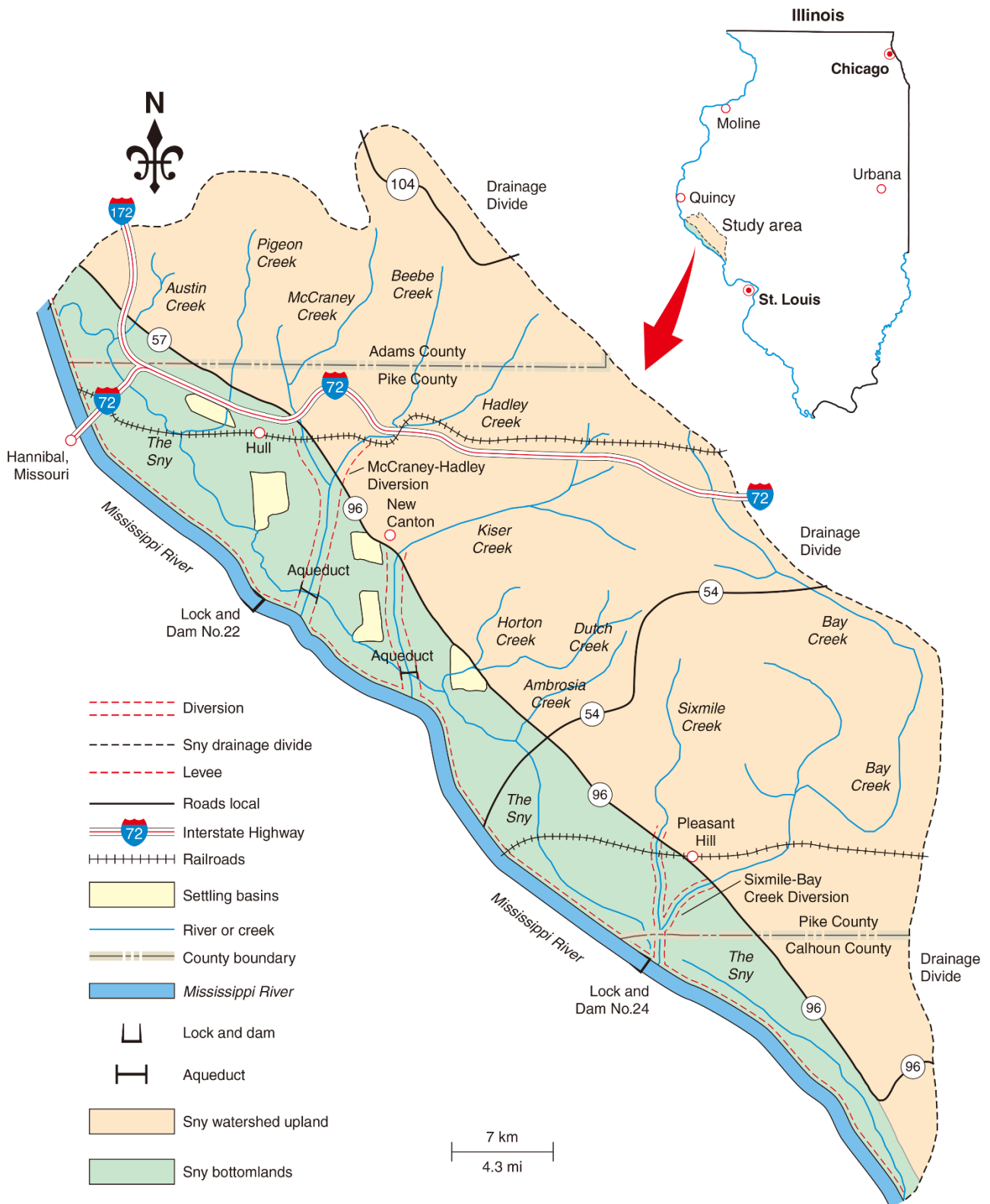
tame the two great rivers and their tributaries for human uses. These case studies portray the human attempts to manage rivers and their bottomlands under intensified agricultural uses, changing settlement patterns, and shifting social values. Each case study presents historical geology and underlying soil and landscape features that frame the convergence of recent flood and drought events, the structures built to contain and manage the river system, and the resulting planned and unexpected consequences. The language of the river and its management represents a distinct culture with meanings that can inspire fear, confidence, and uncertainty: sand boils and sinkholes, river readings on the Cairo gage (**Figure 3**), earthen levees, floodwalls, channel dredging, aqueducts, swamp busting, diversions, levee districts, slurry trenches, relief wells, reservoirs, locks and dams, and floodways. Maps, photographs, and diagrams are extensively used throughout the paper and are central to understanding geography, time scales, and soil and water relationships. These visuals offer valuable illustrations and spatial orientations to the rivers and their surrounding landscapes and provide snapshots in time of historical and current geologic and geopolitical boundaries; levee boundaries; riparian corridors, swamps, and wetlands; and disappearing and emerging lands as the rivers change course.

The primary objectives of the paper are: 1) To document how geological and landscape resources of the Middle Mississippi River have contributed to the successful water resource and economic development of a historically rich region in North America; 2) To identify the anthropic, environmental, and natural resource risks to the Middle Mississippi River basin; 3) To evaluate the proposed environmental and conservation groups attempts change the historic highest and best use, navigation and economic development, of the Middle Mississippi River and watershed.

## 2. Findings

### 2.1. Case Study 1: Multifunctional Middle Mississippi River Leveed Bottomlands and Settling Basins: Sny Island Levee Drainage District

Olson *et al.* [2] found: “*The oldest Drainage District in Illinois, officially established in 1880 shortly after the passage of the current Illinois Drainage Law in 1879, the Sny Island Levee Drainage District (Figure 7) initially included approximately 44,000 ha of floodplain bottomlands with 1600 ha of additional lands annexed later. The drainage district has operated for more than 130 years as a local government levee and drainage district and has been used by the Illinois Supreme Court as a model for the development of other drainage districts formed to enable public assessments for protecting agricultural land and valuable infrastructure from flooding. The US Army Corps of Engineers, which is responsible for the Middle Mississippi River levees as we know them today, has been a key cooperator with the Sny Island Levee Drainage District. The circuit court sets the maximum assessment rate and gives the Sny Island Levee Drainage District the*



**Figure 7.** The Sny River bottomlands and the adjacent uplands watershed, which drains into the Sny River channel. Mic Greenberg created the map. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

*power to assess local farms and landowners in the flood plain who receive a benefit*

*of being protected from Middle Mississippi River and interior flooding by the levee, pump stations, and gravity outlets. The 2008 flooding in the Middle Mississippi River valley did not break any of the levees of the Sny Island Levee Drainage District, and the 56,000 ha of protected bottomlands did not flood. This was not the case in 1993 Middle Mississippi River basin flooding, when the northernmost 16,000 ha of the Sny Island Levee Drainage District protected bottomlands flooded. However, the District levees (Figure 8) and diversion levees in the southern section protected the remaining 40,000 ha of bottomlands from flooding. Assessment funds are used to maintain the levees and drainage systems along the Middle Mississippi River. Parcel assessment is based on elevation and spatial location within the district. The average current assessment rate is \$46 ha<sup>-1</sup>. Three commissioners are elected in alternating years to the drainage district board as landowner representatives responsible for monitoring and managing the drainage district [2].”*



**Figure 8.** The merged Mississippi River and Kiser Creek Diversion levee blocks the Sny River channel flow, and water has to be pumped over the levee to the Mississippi River. Reprinted with permission from the Editor of the Journal of Soil and Water Conservation.

The combination of purposefully created wetlands and settling basins (Figure 9) alongside agricultural lands protected by levees provides diverse habitats for wetland species, fishing, and recreational duck and deer hunting. The high cost per hectare of land assessment pushes producers on both bottomlands and uplands to select high-value crops and to farm right to the edge of their internal drainage ditches. Fast-moving, high water in these ditches increased bank erosion where it is not held by vegetation, clogging the drainage system and increasing the need for more frequent ditching and the Sny River channel dredging. Incentives

to encourage 2 to 3 m vegetative strips along-side these steep ditches are conservation measures that would hold soil in place and reduce the movement of soil from field to water. Much of the upland and bottomland farmland is already in no-till (**Figure 10**), so producers should be encouraged to continue this practice



**Figure 9.** The Pigeon Creek settling basin west of Hull, Illinois, is currently active during high runoff and flooding. Reprinted with permission from the Editor of the Journal of Soil and Water Conservation.



**Figure 10.** Many of the Sny River watershed uplands have no-till corn planted on very steep slopes, which reduces soil erosion into drainage ditches. Reprinted with permission from the Editor of the Journal of Soil and Water Conservation.

and expand it to row crops currently not utilizing this management practice. In addition, the conversion of very steep slopes from row crops to perennial cover would help reduce further soil loss. This, however, does not address an underlying concern—the need for landowners to produce sufficient revenues to cover the drainage district per hectare assessment to protect the region. As the price of fuel oil increases, high agricultural productivity coupled with high commodity prices will be needed.

One possible way to successfully develop the Sny Island water resources and mitigate this treadmill is to build on the diverse habitat created by this system of wetlands, filled sediment basins (**Figure 11**), levees, and purposefully develop an economic tourism plan to increase the recreational use of this region.



**Figure 11.** A filled Sny River settling basin that is 3 m above the land surface. Reprinted with permission from the Editor of the Journal of Soil and Water Conservation.

## 2.2. Case Study 2. Dredging of the Fractured Bedrock-Lined Middle Mississippi River Channel at Thebes, Illinois

Olson and Morton [3] determined: “*The usually abundant slow soaking rain systems and evening thunderstorms that characterize the Great Plains climate from May through August were absent in 2012. As a result, the Ohio and Middle Mississippi rivers dropped to near record levels from July of 2012 through January of 2013, and the US Army Corps of Engineers (USACE) faced a new challenge to their ability to control the Middle Mississippi River. The 2012 drought reduced the channel depths on the Middle Mississippi River between Cairo, Illinois, and St. Louis, Missouri, to only 0.3 to 1.8 m above the 2.7 m deep navigation shipping channel created by USACE in response to the 1930 Rivers and Harbors Act. Of greatest concern was the bedrock-lined river shipping channel near Thebes, Illinois, which threatened to ground barge traffic transporting critical agricultural*

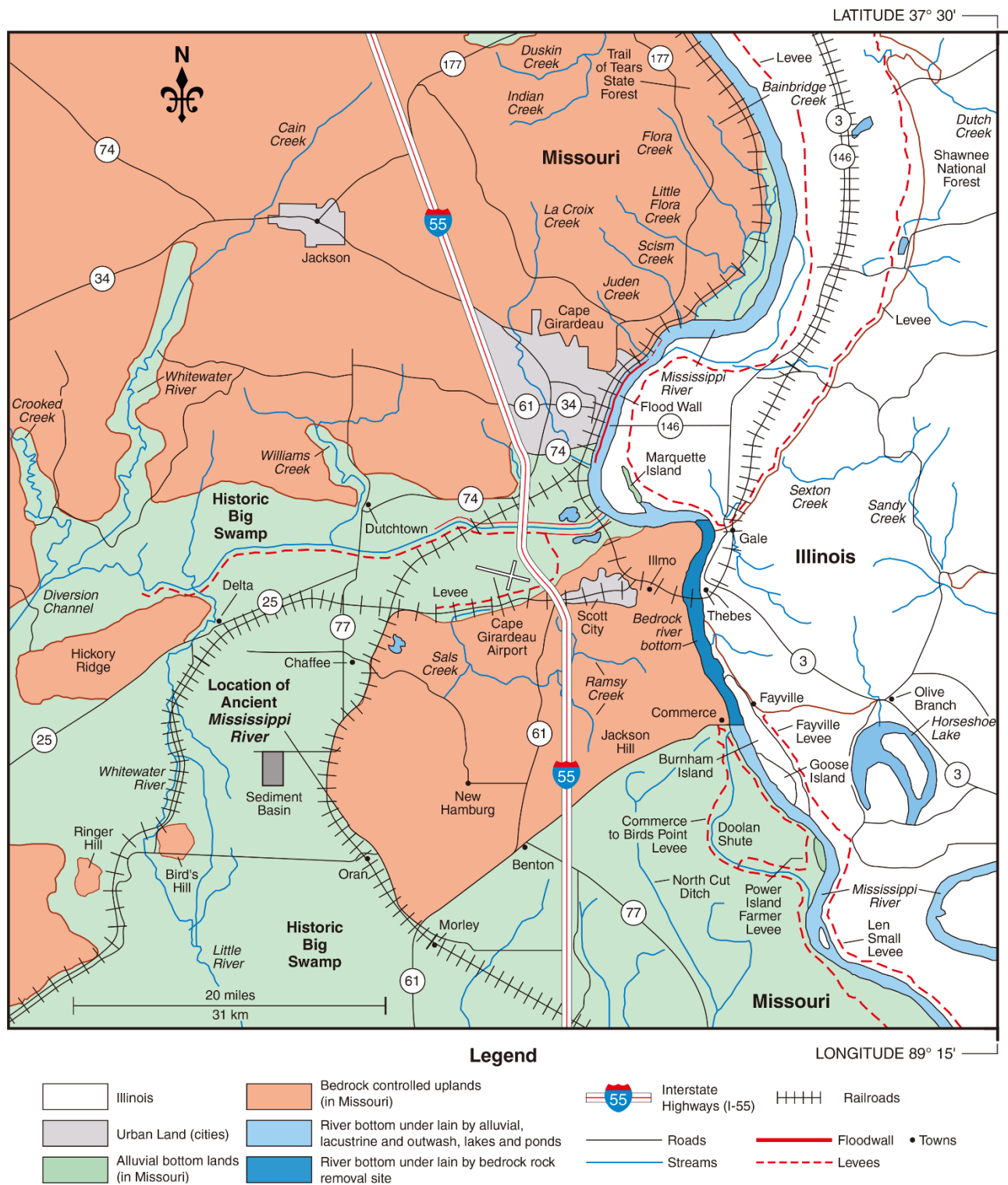
supplies, including fertilizers and grain. Although the USACE systematically surveys the river bottom and routinely dredges any accumulation within the Middle Mississippi River to maintain the shipping channel, the Thebes section of the river posed a more difficult engineering situation. Ice Age glaciers and more recent seismic activity created the ‘Thebes gap’ in the upland bedrock ridge (Figure 12) and rerouted the ancient Mississippi River through, rather than around, the upland bedrock ridge of the former southern Illinois land bridge. Throughout the summer of 2012, as the drought deepened and river levels fell, the USACE increased the removal of sand and other unconsolidated sediments along the Upper and Middle Mississippi navigation channel. However, along the 9.1 km fractured bedrock-lined channel (Figure 13), starting just south of Gale, Illinois, and extending past Thebes, Illinois, to Commerce, Missouri, the underlying river bottom materials required substantive excavating of rock (Figure 14) as the narrow bedrock channel under drought conditions became shallow with hidden and exposed rock, a dangerous obstacle to barge and other boat traffic [3].”

The 2012 central Great Plains drought eclipsed the driest summers of 1934 and 1936 at the height of the Dust Bowl, reduced the water flows of river systems, and severely curtailed commerce on the Upper and Middle Mississippi River [2]. Following early 2011 snowmelt, heavy rains, extreme flooding, and levee breaching along the Upper and Middle Mississippi River, the rapid onset of drought in 2012 was unexpected and challenged the USACE to maintain a safe river depth above the 2.7 m navigation channel for barge traffic. The USACE successfully dredged the Lower Mississippi River to keep the shipping channel open, but those channels were underlain with unconsolidated sediments (sands and alluvial materials) that could be removed with equipment routinely used to maintain the river depths and widths for navigation.

The dredging of the 9.1 km narrow bedrock-lined channel near the town of Thebes, Illinois, required large excavators capable of breaking loose the consolidated river bottom to deepen the channel. The 2.7 m deep and 91 m wide Middle Mississippi River channel was dredged at a time when the excavators (Figure 14) could easily reach the bottom of the shipping lane and were able to restore and maintain the shipping lane for barge traffic as water levels dropped during the drought of 2012 to 2013. Without the dredging work by the USACE, due to low water levels the natural risk to shipping on the Middle Mississippi River was great. All shipping through the Middle Mississippi River corridor would have stopped, possibly for months, which would have been an unacceptable risk to food and national security.

### **2.3. Case Study 3. Impacts of 2011 Len Small Levee Breach on Private and Public Illinois Lands**

Olson and Morton [4] noted: “Agriculture, the dominant land use of the Middle Mississippi River Basin for more than 200 years, has substantively altered the hydrologic cycle and energy budget of the region. Extensive systems of US Army



**Figure 12.** Thebes, Illinois, is located south of Cape Girardeau and Commerce, Missouri, on a narrow, 10-kilometer bedrock-controlled upland stretch of the upper Mississippi River. This location made it an ideal ferry and railroad crossing for commerce between Illinois and Missouri. Map created by Mic Greenberg. Reprinted with permission from Editor of Open Journal of Soil Science.



**Figure 13.** Bedrock was exposed and a threat to navigation on the Mississippi River near the Thebes railroad bridge on December 21, 2012, when the river reached a low of 2 meters. Reprinted with permission from the Editor of the Journal of Soil and Water Conservation.



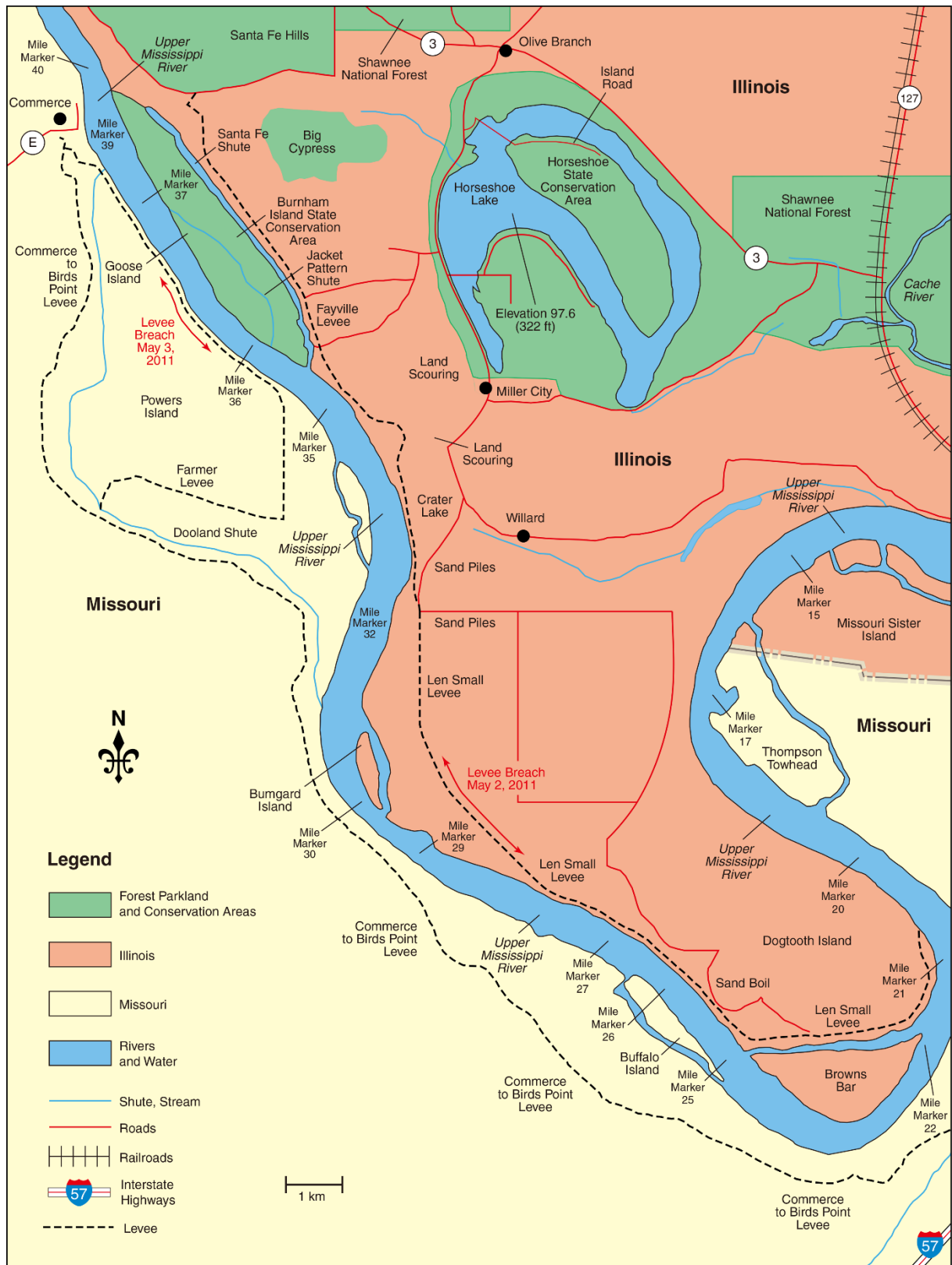
**Figure 14.** River bottom bedrock is dredged using an excavator to increase the navigation depth. Reprinted with permission from the Editor of the Journal of Soil and Water Conservation.

*Corps of Engineers (USACE) and private levees from the Middle Mississippi River near Cape Girardeau, Missouri, southward confine the river and protect low-lying agricultural lands, rural towns, and public conservation areas from flooding. The*

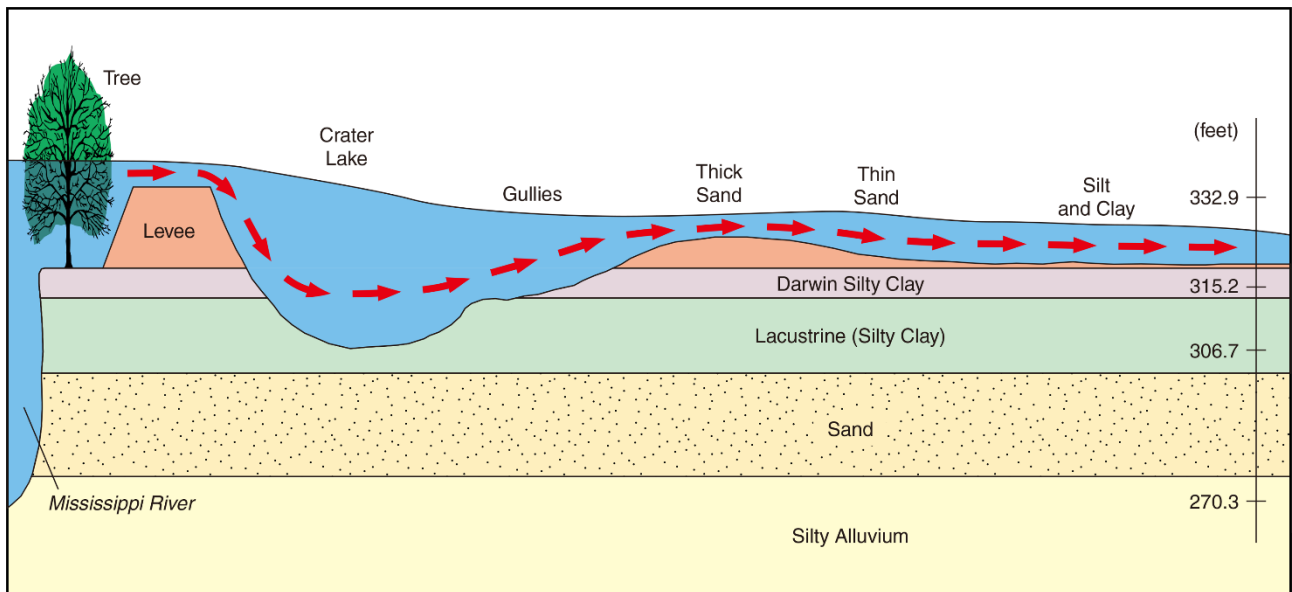
*Flood of 2011 severely tested these systems of levees (Figure 15), challenging public officials and landowners to make difficult decisions, and led to extensive damage to crops, soils, buildings, and homes. One of these critical levees (Figure 16), the Len Small, failed, creating a 1,500 m breach (Figure 17) where fast-moving water scoured farmland, deposited sediment, and created gullies and a crater lake. The Len Small levee, built by the Levee and Drainage District on the southern Illinois border near Cairo to protect private and public lands from 20-year floods, is located between mile marker 21 and mile marker 35 (Figure 15). It connects to Fayetteville levee that extends to Middle Mississippi River mile marker 39, giving them a combined length of 34 km protecting 24,000 ha of farmland and public land, including the Horseshoe Lake Conservation area (Figure 18). The repair of the breached levee, crater lake, gullies, and sand deltas began in October 2011 and continued for one year. In 2011, the record Ohio River flood resulted in the USACE blasting open the Birds Point levee fuse plug as waters reached a critical height on the Cairo gage. However, this unprecedented flood level at the confluence put tremendous pressure on and under the Middle Mississippi levees to the north in western Alexander County. The delay in the decision to blow up the Birds Point fuse plugs and front-line levees had significant consequences for rural Illinois landowners, farmers, and residents in Alexander County near the Len Small levee that failed the morning of May 2, 2011, at a time when the peak flow on the Ohio River caused the Middle Mississippi River water to back up many kilometers to the north. Local flooding and damage to building structures (Figure 19), crops, and soils initially occurred in late April of 2011 when the Ohio River at flood stage poured through the Post Creek cutoff and a previously unrepaired Karnak levee breach and rushed to the west through the middle Cache River valley. Consequently, the town of Olive Branch would have flooded even if the Len Small breach had not occurred [4].”*

The Len Small levee situation does not seem to have been a factor in the USACE decision-making process or have affected the time of the opening of the Birds Point-New Madrid levee fuse plug. The USACE did consider the need to protect the Cairo mainline levee and floodwall (Figure 20) and the Commerce to Birds Point mainline levee from a breach, as well as potential impact on landowners in the Birds Point–New Madrid Floodway. The mega sand boil in Cairo, the heavy local rains on May 1st in the Middle Mississippi River watershed, and the new peak forecast of 19.2 m on the Cairo gage proved the opening of the Floodway was the correct decision. Even if the Birds Point-New Madrid levee had been opened four days sooner at a time when the record level floodwaters were 1.3 m lower, the prolonged record Middle Mississippi River floodwater levels and pressure on the Len Small levee, which continued for weeks, would likely have still resulted in the Len Small levee breach a few days later.

The natural risk of more than 1 million ha of agricultural bottomlands being flooded in Missouri Bootheel and Arkansas was mitigated by the USACE opening of the Birds Point-New Madrid Floodway. The use of the federal floodway reduced



**Figure 15.** This map of the Dogtooth Bend area in southwest Illinois shows the 1993, 2011, and 2016 breach locations and the Mississippi River floodwater overland flow patterns. Map by Mic Greenberg, Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 16.** Diagram of levee topping by the Mississippi River above flood stage, including a crater lake, gullies, and thick sand deposits. Drawing by Mic Greenberg. Reprinted with permission for Editor of Journal of Soil and Water Conservation.



**Figure 17.** The Birds Point levee was the site of the first explosion on May 2, 2011, that opened the New Madrid Floodway and relieved river pressure on the Cairo floodwall. Remnants of the fuse plug levee and the crater lake extend into the adjacent agricultural lands. Photo Credit: Lois Wright Morton. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 18.** Bald cypress trees and American lotus at Horseshoe Lake conservation area provide wetland habitat for local and migratory birds and a recreational destination for fishing, boating, picnicking, camping, and wildlife observation. Photo Credit: Lois Wright Morton. Reprinted with permission from Editor of Journal of Soil and Water.



**Figure 19.** Mississippi flooding at Thebes, Illinois, on January 5, 2016. The floodwaters covered the playground and the riverbanks and flooded homes and businesses that were not on stilts. A tugboat is pushing barges upriver in the background. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 20.** The Cairo floodwall is built on the Ohio River side at the bend in the river where an earthen levee would be difficult to maintain. With the river 3 m above flood stage, a tugboat is visible behind the floodwall. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

the pressure on the frontline Commerce to Birds Point levee which did not fail and protected these agricultural bottomlands in Missouri Bootheel and Arkansas.

#### **2.4. Case Study 4: Missouri Ozark Plateau Headwaters Diversion Engineering Feat**

Olson *et al.* [5] found: “*The Headwaters Diversion (Figure 21), a system of impounding basins, channels, and levees, carries the waters of the eastern Missouri Ozark Plateau hill streams eastward to the Middle Mississippi River south of Cape Girardeau. The system consists of three large basins, 78 km of channels, and 69 km of levees designed in 1910s by the Little River Drainage District (LRDD) to divert and temporarily store ordinary and flood waters running off 288,000 ha of the Francois Mountains and Ozark Plateau uplands. Today, the Headwaters Diversion helps drain and protect 480,000 ha of agricultural lands in southeast Missouri from internal seasonal flooding and Mississippi River backflow at flood stage. It was constructed concurrently with an intricate network of 1500 km of ditches (Figure 22), 375 km of levees, and water detention basins draining thousands of alluvial wetland hectares in the ancient Mississippi River floodplain running south from the diversion levee 144 km to the Arkansas border (Figure 23).*”

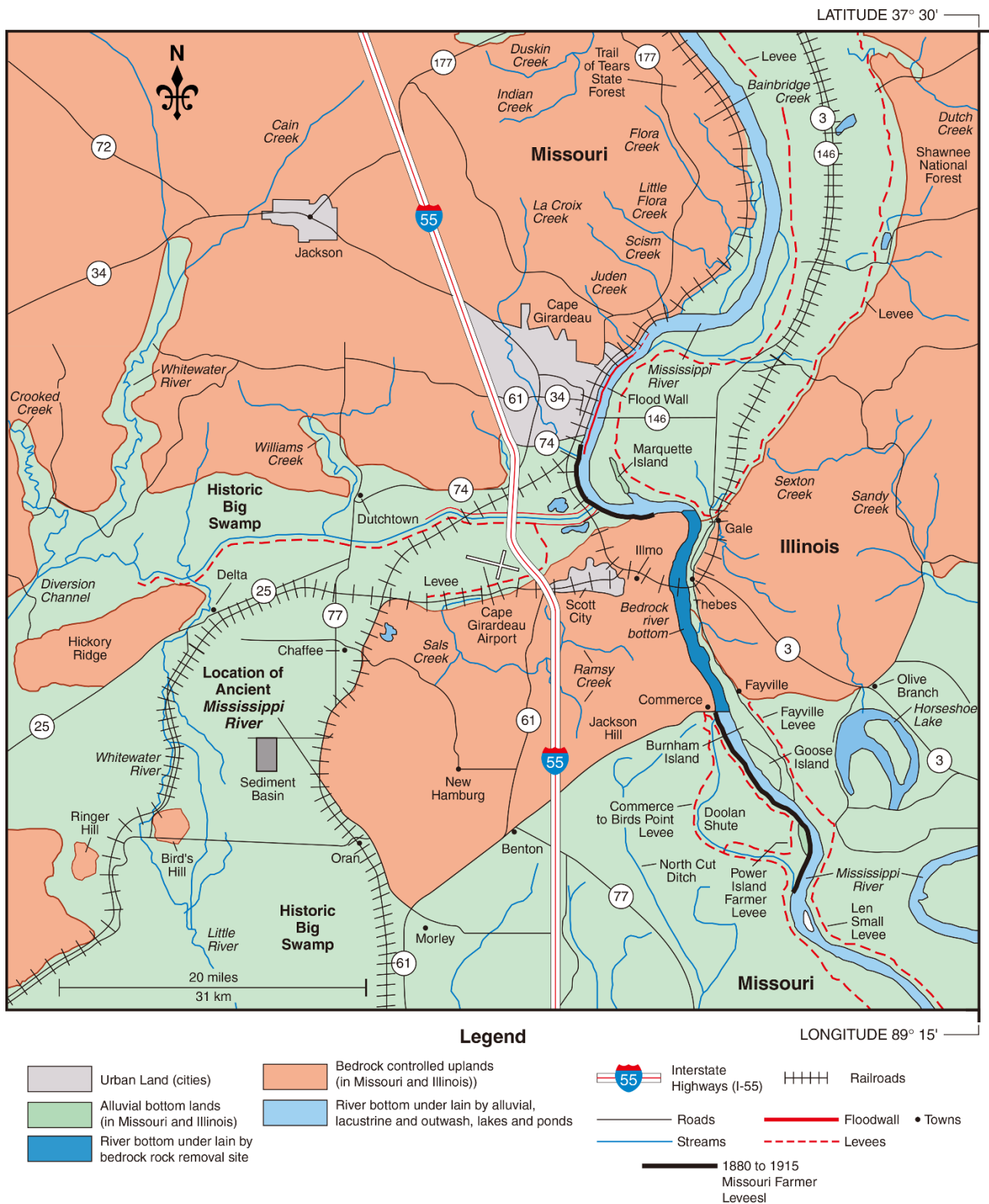
“*Prior to the construction of the 72 km Headwaters Diversion channel, the Castor and Whitewater rivers and Crooked Creek flowed off the elevated plateaus onto the second bottomlands, with waters pooling in the extensive lowlands and depressions of the historic Big Swamp and into the tributaries of the Little River.*



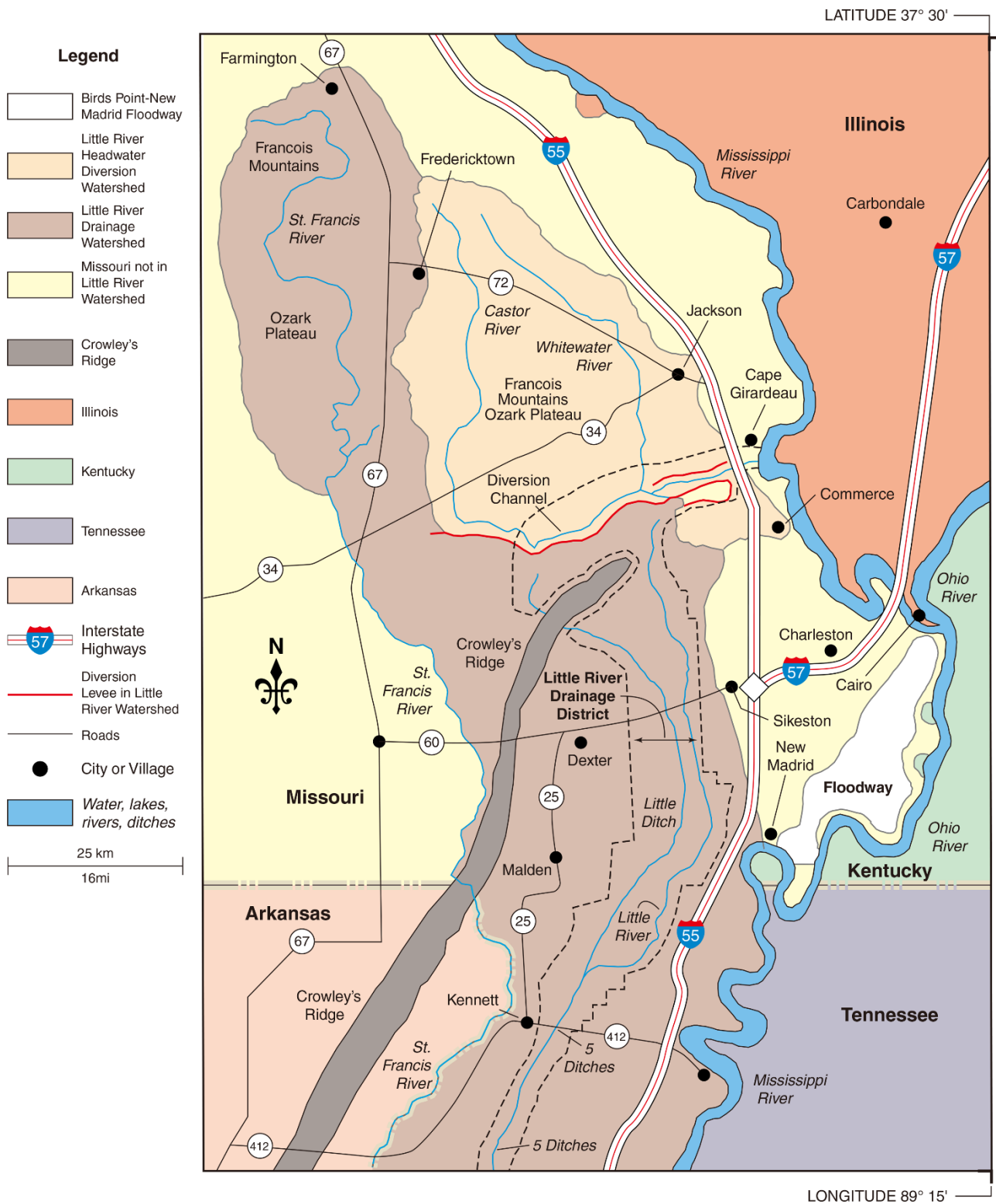
**Figure 21.** The Headwaters Diversion watershed drains Missouri Ozark upland streams southward where they are diverted directly into the Mississippi River south of Cape Girardeau, Missouri, via the diversion channel. Photo Credit: Lois Wright Morton. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

*One-third of this heavily forested alluvial plain was permanently under water, and 70% was under water from two to six months during the year, allowing only 15% of land to be cultivated. During this period, the Little River naturally drained the entire Bootheel region of southeast Missouri into the Arkansas-White-Red River basin. Labeled one of the world's largest land reclamation projects, the draining of over 480,000 ha of swampland transformed southeast Missouri lowlands into a rich agricultural region known for soybeans (*Glycine max* [L.] Merr.), wheat (*Triticum aestivum* L.), sorghum (*Sorghum bicolor* [L.] Moench), rice (*Oryza sativa* L.), cotton (*Gossypium hirsutum* L.), peaches (*Prunus persica*), and watermelons (*Citrullus lanatus*). Central to the success of this engineering feat was the diversion of water, originating in the Ozark Plateau and Francois Mountains (Figure 24), directly into the Middle Mississippi River using a series of leveed channels. The intent of this diversion in the northeastern corner of the LRDD was to isolate the upper basin and prevent overloading of the lower drainage system constructed to drain the low-gradient, slow-moving waters in the historic river floodplain south [5]."*

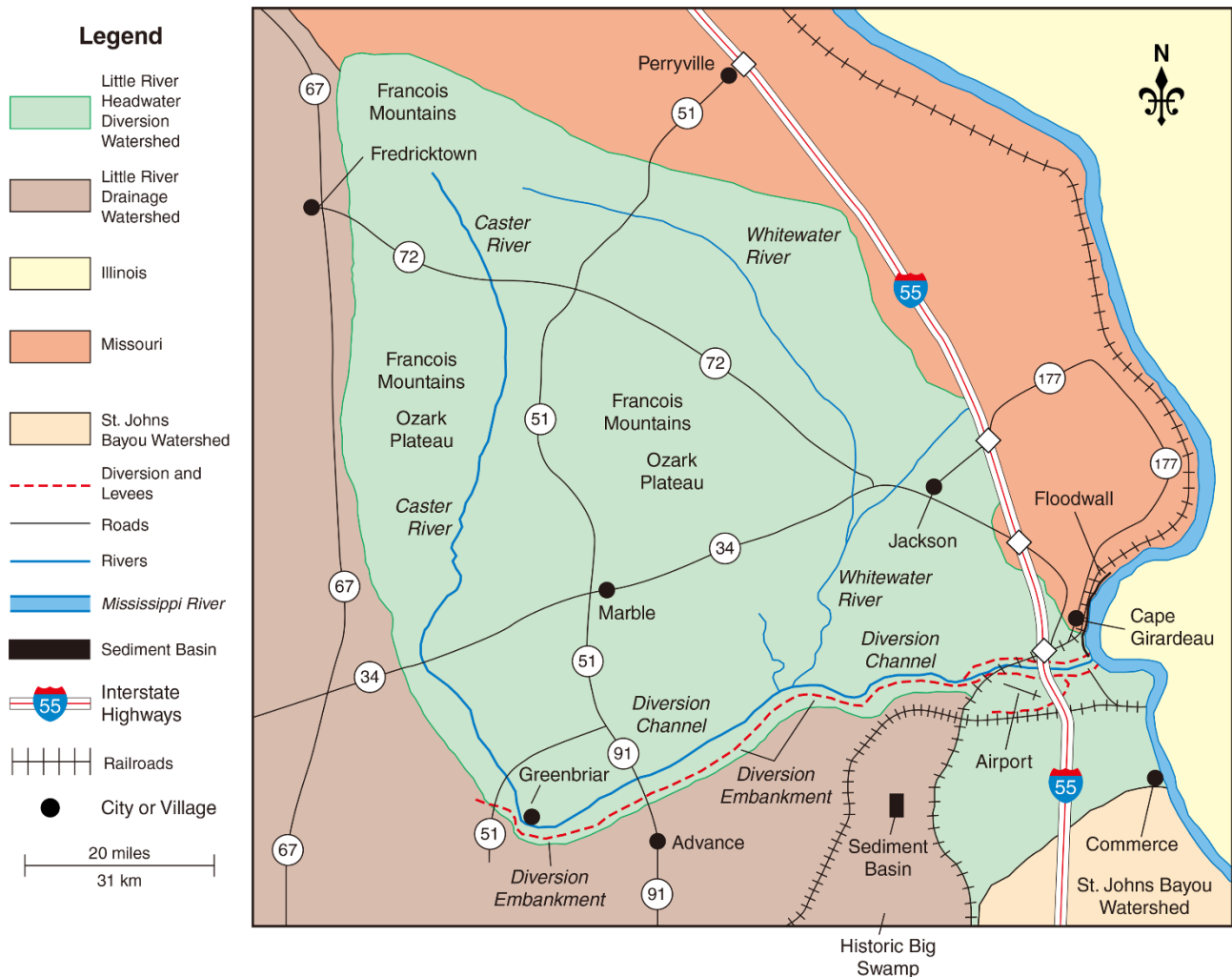
Construction of levees, diversions, and floodways, and land use conversion from wetlands to agriculture for the last 200 years, have substantively altered the hydrologic cycle of the region. The Little River levee and LRDD Headwaters Diversion channel built in the 1910s successfully permitted the drainage of the 800,000 ha Big Swamp (Figure 25) in the Bootheel of Missouri. However, it also had the unintended consequence of increasing the flow and peak of Mississippi River water south of Cape Girardeau through the Thebes gap and south to Helena, Arkansas, approximately 576 river kilometers (Figure 23). When the Ozark



**Figure 22.** The Headwaters Diversion channel (red dashed line in Historic Big Swamp) helped drain the Big Swamp and currently protects agricultural lands to the south from flooding by diverting the floodwaters directly to the Middle Mississippi River. Map created by Mic Greenberg. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 23.** At the eastern base of Crowley's Ridge are fertile soils that are irrigated during dry periods. Forested land is in background. Map created by Mic Greenberg. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 24.** This Little River Drainage District map shows the Ozark Plateau in the Headwaters Diversion watershed that drains into the diversion channel and the Mississippi River south of Cape Girardeau. The upland and bottomland areas west and south of the Headwaters Diversion watershed drain into the St. Francis River. Map created by Mic Greenberg. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

uplands and Francois Mountains experience above average rainfall for extended periods, the additional runoff transported by the diversion channel (approximately  $270,000 \text{ ha}\cdot\text{m}\cdot\text{y}^{-1}$ ) increases the chances of Middle Mississippi River levee breaches south of Commerce, Missouri, and adds to the peak river height at the confluence of the Ohio and Middle Mississippi rivers [5].

The increase in Mississippi River peak flow placed additional river pressure on levees and led to increased flooding, especially during the floods of 1927, 1937, and 2011. The Kentucky, Illinois, and Missouri farmers' and landowners' response to the additional volume and height of the Middle Mississippi River from the diversion channel valley and the prevention of the Mississippi River floodwaters from flowing into the ancient Mississippi River valley and Big Swamp was to build floodwalls and levees. Cape Girardeau, after 1915, experienced repeated flooding and built a floodwall to protect the city. The Great Flood of 1927 resulted in Cairo

building a floodwall and strengthening levees and the creation of the Birds Point-New Madrid floodway. The Len Small (built in 1943)-Fayville (built in 1969) farmer levee in Illinois [5], the Hickman levee in Kentucky, and the Commerce farmer levee in Missouri were also constructed and strengthened after the completion of the Headwaters Diversion. Over time, the Kentucky landowners were able to get the USACE to strengthen the mainline Hickman levee, which did not fail in either 1993 or 2011. However, the Len Small-Fayville levee failed in 1993, and both the Commerce farmer and Len Small-Fayville levees failed during the 2011 flood. Climate scientists predict a continued pattern of extreme rainfall events in the upper Mississippi River region. This suggests that unexpected above average rainfall events in uplands and floodplains will continue to add to the high peak flows in the Mississippi River. There is a need for additional floodwater storage in the greater Ohio-Mississippi river confluence area.

A regional effort on both sides of the Ohio and Mississippi rivers is needed to successfully develop water resources by 1) identifying floodplain areas that could provide temporary water storage and 2) developing policy and economic incentives for landowners of low-lying lands to profitably invest in crops and income alternatives.

### **2.5. Case Study 5: Little River Drainage District Conversion of Big Swamp to Fertile Agricultural Land**

Olson *et al.* [6] determined: “*More than a century ago, American swamps and river lowlands were considered wasteland of no value and a hindrance to land development. The Swamp Land Acts of 1849, 1850, and 1860 granted states the right to reclaim 26 million ha of swamps through the construction of levees and open channels (ditches) (Figure 26) to control flooding; to encourage settlement, land cultivation, and commerce; and to eliminate widespread mosquito breeding. Southeast Missouri, once one of the world’s largest tracts of forested bottomlands, was a vast wilderness of bald cypress (*Taxodium distichum L.*), tupelo (gum; *Nyssa L.*), hardwoods, and water, barely accessible to settlers migrating west. In the early 1890s, these historic river floodplains (Figure 27) and their tributaries were drained and transformed into fertile agricultural lands in an ambitious engineering feat comparable to the construction of the Panama Canal. Today, this vast network of ditches (Figure 28), channels, and levees in southeast Missouri bottomlands makes possible an intensive system of agriculture, which produces almost a third of Missouri’s agricultural economic output and has changed the hydrology, nutrient cycling, biodiversity, and structure of the entire ecosystem. Unified and managed by the Little River Drainage District with support from the US Army Corps of Engineers (USACE), this region drains 208,000 ha of bottomlands and is the drainage outlet for the runoff from 480,000 ha of bottomlands and uplands to the Mississippi River at Helena, Arkansas. The LRDD is comprised of an west-east headwaters diversion system of 288,000 ha, which drains the northeast lands directly to the Mississippi River at Cape Girardeau, and a complex north-*

*south drainage system collecting runoff from 480,000 ha of agricultural and forest lands with 1540 km of ditches draining 208,000 ha of LRDD bottomlands running south from the diversion channel to the Arkansas border [6].”*

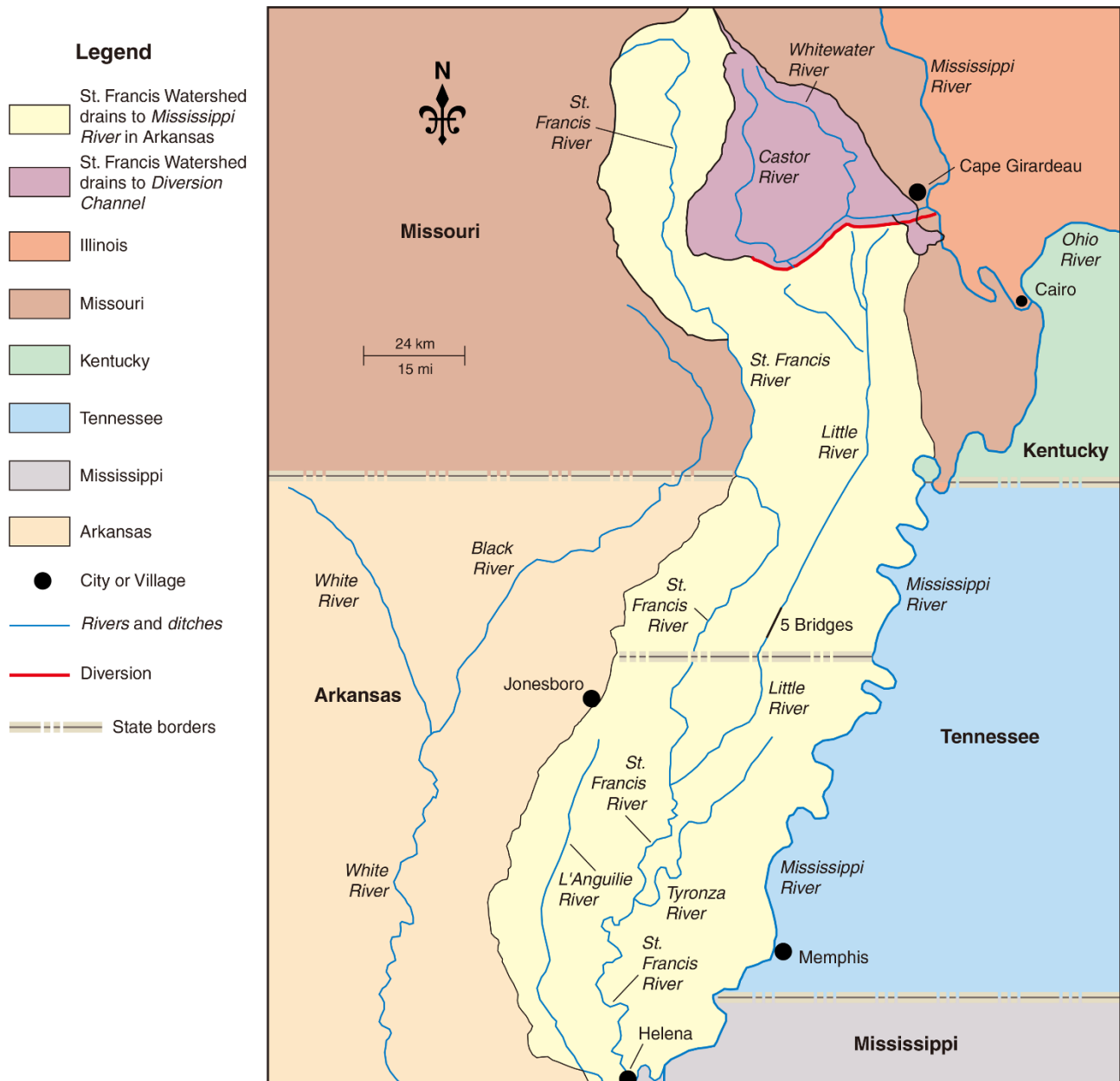
Had the conversion been delayed for 100 years, the area would probably have become a federally protected wetland preserve [6]. Advances in agriculture and



**Figure 25.** The Mingo National Wildlife Refuge, a 8660 hectare bottomland preserve, is a small restored remnant of the original 0.5 million-hectare Missouri Swamp that was transformed into fertile agricultural lands by extensive drainage systems in the early 1900s. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 26.** Agricultural lands created by draining Big Swamp. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 27.** The St. Francis River watershed drains southeast Missouri and eastern Arkansas. The Little River becomes a tributary of the St. Francis River in Arkansas before draining into the Mississippi River at Helena, Arkansas. Map created by Mic Greenberg. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

water management have helped engineers better understand how to manage artificially drained low-gradient agricultural lands. However, the tension between wetland services and agricultural land uses will continue to increase and be a future challenge that the LRDD will need to address to find some level of balance among competing economic, social, and biophysical conditions. LRDD oversight of so many thousands of hectares well positions LRDD to evaluate and address the landscape-wide vulnerability of drained and levee-protected lands from interior and river flooding as precipitation and extreme and variable weather stress



**Figure 28.** Five drainage ditches run parallel in southern Little River Drainage District just north and east of the Arkansas border. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

their infrastructure and affect downstream communities.

Without continual maintenance and repair of ditches and levees, these Mississippi River bottomlands have a predisposition to flood farmland seasonally and revert to the wetlands of the past. Further, the straightening of streams and channelization of water to move water off fields is a source of soil erosion and bank scouring that needs constant attention to control sedimentation throughout the system. One of the big challenges that Mississippi River drainage districts and the USACE face is how to best manage the water velocity and emergent vegetation in their drainage systems to control seasonal flooding, keep the channel beds stable, and reduce off-field and landscape-wide nutrient losses while creating habitat diversity under seasonal drought and uncertain climate patterns [6]. The 2007 LRDD report [6] celebrating their 100-year anniversary well summarizes the changes that have occurred and the challenges that continue into the future: “*This region was once a bog, a swamp, a lowland, a morass, a hunting and fishing paradise, a no man’s land, an endless stretch of virgin hardwood timber, a moss, a stillness that stole the sleep from the tired, a hideout, a barrier, a challenge to do the impossible. Today a traveler driving across the areas could never know of these things as he or she passes field after field laid out on a perfect grid, interrupted only occasionally by a narrow bridge every mile or so. Below them, however, the swamp does not sleep and labors to regain itself, held only at bay by the never-ending work of men and women of the Little River Drainage District.*”

The LRDD intricate system of drainage ditches reduced the risk of flooding by moving more than 117.3 million L of water annually off the land and into the Mississippi River. The drainage district’s investments in the Headwaters Diversion channel, levees, and ditches, along with the construction of the Thebes railroad bridge [6], created an economic and technological engine that resulted in the successful conversion of the Big Swamp to productive agricultural lands during the past 111 years.

## 2.6. Case Study 6: Middle Mississippi River Threatens to Make Dogtooth Bend Peninsula in Illinois an Island

Olson and Morton [7] noted: “*The receding floodwaters of the Middle Mississippi River in January of 2016 left behind barren sand dunes on southern Illinois farmland reminiscent of the wind-swept dunes of the movie Lawrence of Arabia (Figure 29). Large sand deposits up to 1.3 m deep covered nearly 800 ha of farmland south of Miller City, Illinois, in the Dogtooth Bend peninsula. Rainfall almost three times above average in November and December of 2015 over Missouri set in motion record flooding with the Cape Girardeau River gage breaking the 1993 record at 14.89 m and led to the breaching of Len Small levee on January 2, 2016. Floodwaters cut deep craters and scoured the landscape as they poured through the breach at mile marker 34 and then followed an old meander channel across the narrow neck of Dogtooth Bend peninsula to reconnect with the Middle Mississippi River at mile marker 15 (Figure 30). Levee breaches and land scouring*

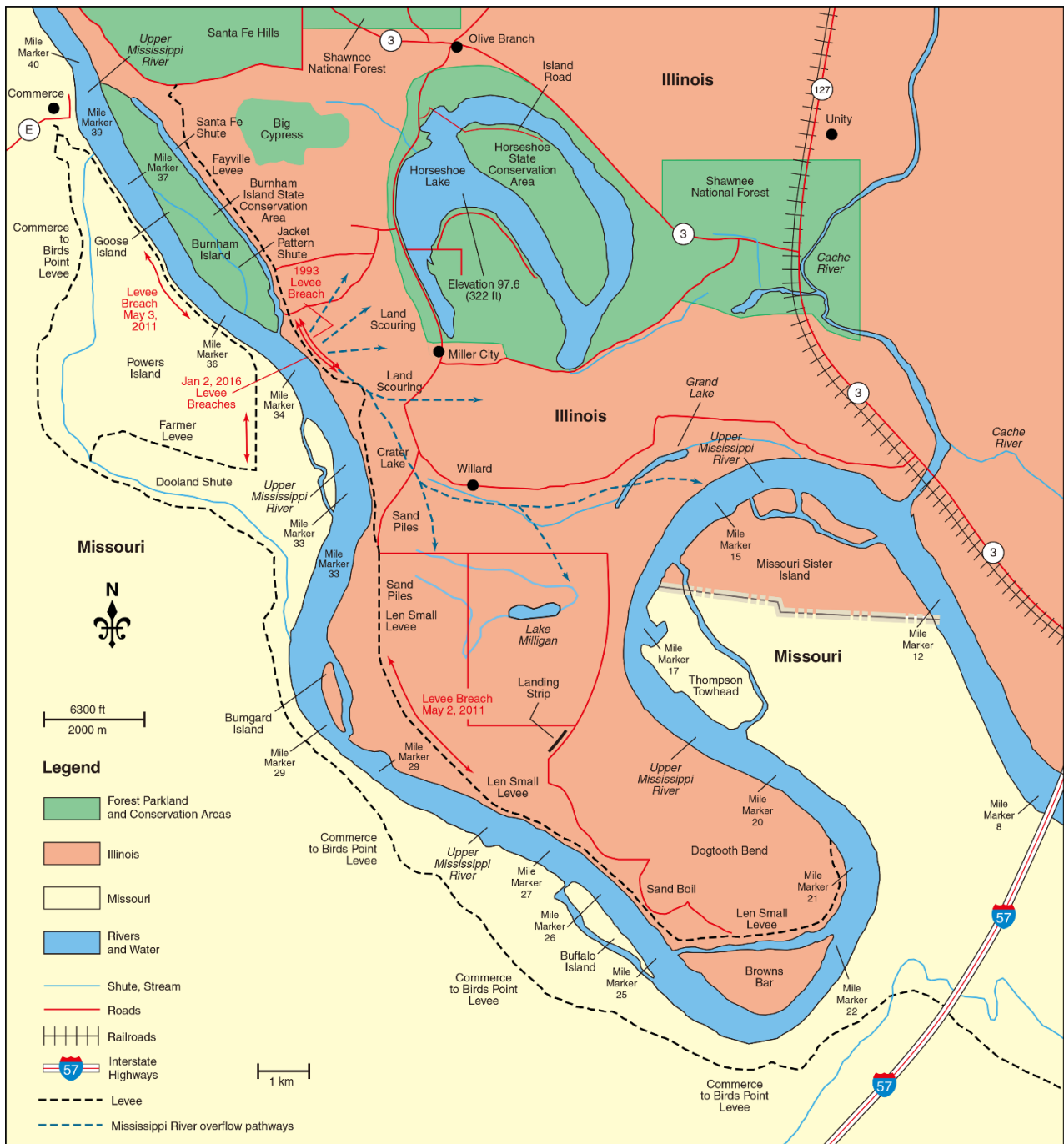


**Figure 29.** Mississippi River floodwaters deposited many tons of sand on farmland and roads in Dogtooth Bend peninsula when the Len Small levee breached in January of 2016. The sand dunes left behind required graders and snowplows to open the road for local traffic. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

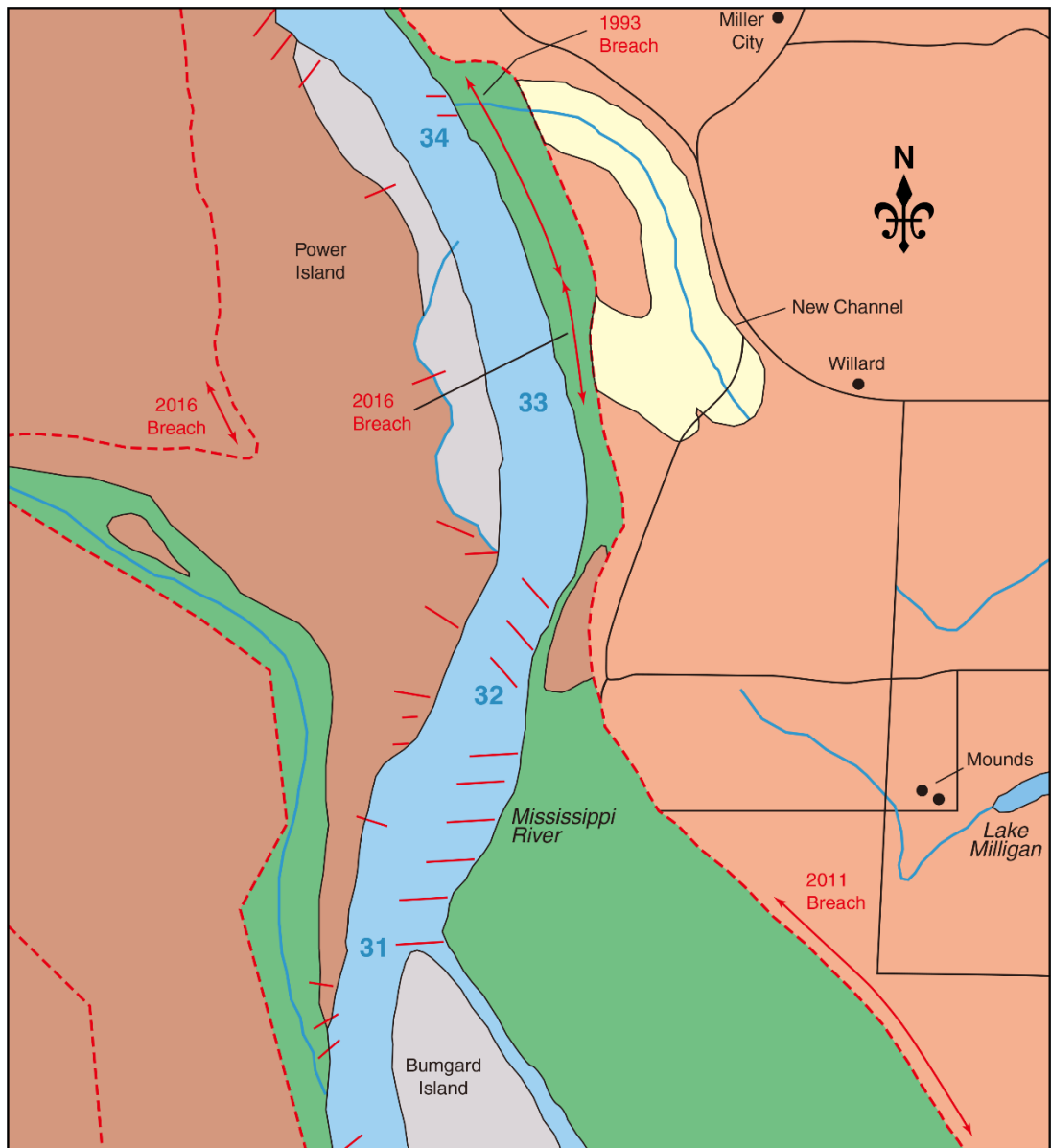
*are not new events for this region, occurring in 1993, 2011, and 2016; and there is high likelihood these farmlands will experience similar events in the future. Each event deepens the meander channel when the floodwaters take a 4.6 km shortcut and threaten to permanently reroute the Mississippi River leaving Dogtooth Bend peninsula an island. This would result in landowners and farmers of 6,000 ha in the Dogtooth Bend area no longer having road access to their land if the Middle Mississippi River realigns naturally. In some cases, the land use would likely shift from agriculture to other uses [7].”*

Prior to the construction of the farmer (Len Small–Fayville) levee in Illinois and the farmer (Commerce to Birds Point) levee in Missouri, the Middle Mississippi River was 16 km wide between mile markers 39 and 15 (**Figure 31**). The creation of these two levees restricted the Middle Mississippi River floodplain to less than 2 km and increased the peak height of the river during flooding events that occurred after 1943. The resulting increased river velocity and height place both levees, as well as downstream levees, at risk of failure. The USACE/MRC mission includes the maintenance of the mainline levees that protect Cairo, Illinois, and the Illinois, Missouri, Kentucky, and Arkansas bottomlands and the maintenance of navigation on the Mississippi River.











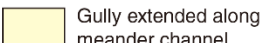
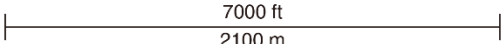
The USACE cannot strengthen the existing Len Small–Fayville levee without increasing the risk of losing their own mainline levees (Cairo levee and floodwall, the Commerce to Birds Point levee and the New Madrid Floodway setback levee). If the Cairo floodwall and levee were to fail, it would put nearly 3000 residents



**Figure 30.** This map of the Dogtooth Bend area in southwest Illinois shows the 1993, 2011, and 2016 breach locations and the Mississippi River floodwater overland flow patterns. The blue dotted line represents a new channel cutting through southeast Alexander County and floodwaters flowing north of Lake Milligan and then exiting into the Mississippi River at mile marker 15. Map by Mic Greenberg. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Legend**

- |  |  |
|--|--|
|  Water ( <i>Mississippi River and waterways</i> ) |  Weirs              |
|  Sand   |  Levee             |
|  Woodland   |  Roads             |
|  Agricultural Land                                |  Village and Mounds |
|  Sand covered agricultural land in Illinois       |  River mile markers |
|  Gully extended along meander channel             |  |
- 
  
 7000 ft  
 2100 m

**Figure 31.** A close-up map of the 2016 Len Small levee breach on the Mississippi River from mile marker 34 to 30. Floodwaters poured through the breach depositing sand over a large part of the area and created the new channel shown on the map (yellow area). Map by Mic Greenberg.

and 400 structures at risk. If the Commerce to Birds Point levee or the New Madrid Floodway setback levee were to fail, 800,000 ha in Missouri, Kentucky, and Arkansas bottomlands could be flooded with both crops and soils damaged.

The opening of the New Madrid Floodway can be used to reduce the pressure and peak height by as much as 1.2 m on confluence area levees [7]. The floodway was used in 1937 and 2011. There is a need for additional floodwater storage in the confluence area of the greater Ohio and Middle Mississippi rivers [7]. A regional effort on both sides of the Ohio and Middle Mississippi rivers is needed to strategically identify floodplain areas that could provide temporary water storage and policy incentives for landowners of low-lying lands to profitably invest in crops and income alternatives. Climate scientists predict a continued pattern of extreme rainfall events in the upper Mississippi River region [7]. This suggests that unexpected above-average rainfall events in the Ohio and Mississippi river basins will continue to increase the frequency of extreme flooding events on these great rivers. As the frequency of intense precipitation events increases, the current Illinois and Missouri farmer levee systems are likely to repeatedly fail if restored to the previous height and strength. The current solution to prevent flooding in the Dogtooth Bend area is not working.

Whatever solutions are chosen, there will need to be a significant investment of human and financial resources to prepare for the future. The risk of flooding agricultural lands and crop loss on Dogtooth Bend is too great without a restored levee. The only other viable solution appears to be a land use change to wildlife and recreational use. There is an on-going effort by the state to purchase and remove all the existing homes and structures to reduce the damage cost from periodic major flooding. In addition, conservation groups are leasing the agricultural lands from farmers, changing the land use, and restoring the wetlands and natural floodplain to address the problem.

### **2.7. Case Study 7. St. Johns Levee and Drainage District Attempt to Mitigate Internal Flooding**

Morton and Olson [8] observed “*When the Lower Mississippi River reached 87.9 m above sea level near New Madrid, Missouri, bottomlands adjacent to the river and farmland, roads, ditches and wetlands begin to flood. Concurrently, at the lower end of the New Madrid Floodway the rising Mississippi backed up into Main Ditch (Figure 32), the 454 m gap in the frontline levee designed to drain the Floodway and St. Johns Levee and Drainage District to the river. When this occurred, the Main Ditch gates on the setback levee (Figure 33) were closed to protect the St. Johns Bayou basin from Mississippi River backflow. However, with the Main Ditch gates closed, precipitation within the basin has no outlet as it drained to the Main Ditch channel. This caused tributary streams to back up and flood a portion of agricultural lands and the town of East Prairie, Missouri. For example, the 19 cm of rain during the first three days of May of 2011 backed up local floodwater in the St. Johns Bayou basin all the way to East Prairie. The*



**Figure 32.** A riverboat on the Mississippi River can be seen passing the outlet of Main Ditch that drains through the 457-meter frontline levee gap at New Madrid, Missouri, to the Mississippi River. Reprinted with permission from Editor of Journal of Soil and Water Conservation.



**Figure 33.** When open, the New Madrid Floodway setback levee gate drains the 80,937-hectare St. Johns Bayou basin to Main Ditch and into the Mississippi River. It is closed under flood conditions to prevent Mississippi River backup water from flowing into the basin. Reprinted with permission from Editor of Journal of Soil and Water Conservation.

*construction of the Commerce to Birds Point to New Madrid levees artificially separated lands within St. Johns Bayou basin and the New Madrid Floodway from*

*their natural drainage paths to the Mississippi River. While much of the farmland behind these levee systems were protected when the waters of the Ohio and Lower Mississippi rivers exceeded flood stage, thousands of hectares of bottomlands were flooded through the gap in the lower New Madrid Floodway frontline levee. In addition, the closure of the setback levee gates at the gap resulted in thousands of hectares in St. Johns Bayou basin being internally flooded. Whenever heavy snowmelt and prolonged rains occur in the Upper and Middle Mississippi and Ohio river valleys, the people of this region watched the river gage numbers with concern for high water river pressure threats to their levee systems and internal flooding of low-lying areas from drainageways. The United States Army Corps of Engineers (USACE) had responsibilities for many aspects of the Mississippi River including flood control, river navigation, and floodplain ecosystems. In recent years, USACE flood mitigation planning in the Bootheel of Missouri has attempted to reduce the number of days communities were isolated by floodwaters, limit crop and non-crop losses, and reduce damage to critical infrastructure by adopting flexible strategies that reconnect the hydrology of the floodplain to the river.*

*The construction of levees and the Birds Point–New Madrid Floodway separated the land in the floodway and St. Johns Bayou basins from their natural drainage pathways. The St. Johns Levee and Drainage District tried for 83 years to regain access to drain local basin internal floodwater directly to the Lower Mississippi River. Once the floodway setback levee was built, local landowners within the floodway had to sign easements, in 1930s and 1960s, giving USACE the right to pass floodwater over their land. If the floodway had never been built, both the St. Johns Bayou and New Madrid Floodway basin farmers would still have been affected by Mississippi River floodwaters every time the river reached flood stage. However, when the setback levee gate is closed there is no effective way for the local St. Johns Bayou basin runoff to drain to the Lower Mississippi River. If the St. Johns Bayou phase of the USACE project is built, it would appear to allow the local St. Johns Bayou basin floodwater to be pumped over the setback levee during the times when the gate is closed. This should reduce internal flooding in the St. Johns Bayou basin, which has adversely affected agricultural production and constrained the intensification of agricultural land use. A primary USACE goal of the US\$170million project was to reduce river backwater flooding at the lower end of the floodway to provide year-round access to agricultural roads and fields and protect against lost crops and residential damage when seasonal flooding occurred. However, closing the floodway frontline levee gap effectively disconnected the hydrology of the floodway wetlands, including Big Oak Tree State Park, from the river and impacted wetland habitat (Figure 18), waterfowl, shorebirds, fish spawning, and other riverine species that move into flooded areas during spring floods. The USACE project attempts to both mitigate the internal flooding experienced in St. Johns Bayou basin and to mitigate the impact on the hydrology of the floodway wetlands, waterfowl, shore bird, fish spawning and other riverine*

*species. The project mitigations would not be met by funding the St. Johns Bayou basin phase only. Both mitigation goals could be met if both St. Johns Bayou and floodway gap closing phases of the project are implemented, including land use change, drainage ditch realignment, and building pump stations in both basins [8].”*

One of the USACE’s greatest challenges is to manage variable river conditions—the uncertainties associated with the concentration and flow of water, and unpredictable weather and changing climate conditions—while balancing diverse and competing river commerce, agricultural, residential, and environmental interests. The building of the floodway introduced a new era in engineering design, moving from the confinement of levees only [9] to a dispersion strategy that allowed the river to temporarily spill into its natural bottomlands to relieve flooding pressures on urban settlements and downstream levees [10]. Paradoxically, these infrastructure investments intended to reduce direct risks of flooding have led to interior flooding problems and unexpected consequences to the larger ecosystem. Levees have been a critical infrastructure in opening new lands to agricultural production, but they may be inadequate as the distribution, seasonality and intensity of precipitation patterns change the economic and social constraints the Middle Mississippi River floodplains are not likely to be fully restored as wetlands to mitigate flood hazards.

To reduce the anthropic, environmental, and natural resource risks, there is a need for a new kind of engineering, one that offers greater resilience to the floodplain system [11]. Resilience engineering goes beyond the levees and floodway structures to strategically reconnect the hydrology of levee-protected lands, portions of former wetlands, and the river, thereby ensuring valuable and necessary ecological functions, such as floodwater storage and wildlife habitat, are in place to absorb future uncertainties associated with flooding.

### **3. Discussion**

Whenever levees on the Ohio or Middle Mississippi rivers are breached, there is soil damage in the flooded areas that impacts agricultural management capacities and crop productivity [12]. Floodwaters coat the entire flooded land surface with sediments which include a variety of pollutants, nutrients and contaminants. The nature of the sediments in floodwaters varies with the topographical and land use characteristics of the watershed. The soil types, hydro-geologic features, volume of flow, time of year, agricultural use of fertilizers, pesticides, and other chemicals as well as upstream point sources such as sewage treatment plants, storm sewer drainage and other urban land uses will affect the extent of the contamination and fine scale remediation needed. Preliminary characterization and measurement of soils and sediment deposit at three locations that experienced recent natural and man induced levee breaches are analyzed to identify patterns of soil and crop damage. These findings provide guidance to the restoration of craters, gullies, land scoured areas and contaminated sediment depositional sites with a goal to im-

prove decision-making, risk analysis and remedial effectiveness. Recommendations include: 1) Improve characterization and measurement of eroded soils and distribution of sediment contaminants after levee breaching; 2) Assess contamination effects on soil productivity and long term agricultural production in order to understand the impacts of flooding on agricultural soils; 3) Evaluate reconstruction investments needed to repair levees based on return of the land to productivity and increased landscape resilience by reducing vulnerability to future flooding and levee breaching stress.

Extreme flooding events such as the 2008 and 2011 floods along the Mississippi and Ohio rivers and their tributaries well illustrate the continuing challenges of public (USACE) and private levee districts attempts to anticipate risk and manage emergency and evolving natural disasters associated with downstream flooding and increased pressure on levee protected bottomlands [12]. Further, there is substantive evidence that the frequency and severity of extreme weather events is increasing and leading to expectations that 50-, 100- and 500-year flood events will occur more often. Of particular concern is the vulnerability of low-lying deltaic environments which are levee protected and the direct impacts of levee breaching on soil erosion, land scouring, sediment contamination and distribution and the indirect impacts on socio-economic activities, particularly agriculture of flooded areas.

Natural and induced levee breaches on Ohio and Middle Mississippi rivers have resulted in short-term and long-term soil contamination and agricultural crop damage. When floodwaters coat the land surface inside former levee-protected landscapes, sediment-laden waters leave behind a variety of pollutants, nutrients and contaminants that can alter the productivity of the area. The nature of these pollutants, nutrients and contaminants in floodwaters and damage to soil varies with the volume and speed of water rushing through the breach and the topographical and land use characteristics of the watershed. The soil types, hydro-geologic features, time of year, agricultural use of fertilizers, pesticides and other chemicals as well as upstream point sources such as sewage treatment plants, storm sewer drainage and other urban land uses affect the extent of the contamination and fine scale remediation needed.

This paper documents the nature of soil degradation and contamination from flooding. Seven case studies in the Middle Mississippi River basin are presented to illustrate the impacts of levee breaching on soil resources and the capacity of the larger landscape to be resilient while retaining agricultural productivity and managing for future flooding events. As a result of our analyses of natural and man induced levee breaches recommendations are made to: 1) Improve characterization and measurement of eroded soils and distribution of sediment contaminants after levee breaching; 2) Assess contamination effects on soil productivity and long-term agricultural production; 3) Re-assess current levee location and design in response to expected future increase in extreme weather patterns (flooding and drought) and changing climate conditions. Alternative designs are suggested

that incorporate natural wetlands and bottomlands to reduce water pressure on levee systems; increase water storage capacity; reduce social, biophysical and economic impacts of soil degradation and contamination; and improve the overall resilience of agricultural productivity in deltaic environments.

Better data and assessment of soil conditions post-flooding 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. Further, better understanding of soil and crop damage can provide levee districts with valuable feedback as they address short-term structural strengthening and repairs and put in place strategic landscape level designs including levee and floodway re-alignment or land use changes that adapt to changing future weather extremes and uncertainties.

Three recommendations emerge from the documentation and analyses of the twelve breached levee case studies, whether they are natural or induced. First, there is a need for improved characterization and measurement of eroded soils and distribution of sediment contaminants after levee breaching. Soil survey maps should be updated by conducting initial inventory and characterization activities and delineation of eroded soils and sediment contaminated sites.

The re-mapping to National Cooperative Soil standards is important since some soils will have been destroyed, some will move to an eroded phase of a soil series and others will have significant sediment deposition which can affect soil productivity and crop yields. In addition, key biogeochemical processes should be measured, such as sand boils, soil erosion, transport, land scouring (including crater lakes, gullies) and thick contaminated sediment (sand) deposition at a scale of 1:15,840. Gully lands are extremely difficult to reclaim, and it is often not clear how the land can be fully restored. The total amount of soil loss in metric tons must be calculated and sources of replacement soil must be found. Replacement soil is difficult and costly to locate and haul to fill in all the deep gullies. Another consideration is the potential to re-grade the vertical walls of gully fields and re-shape the fields into smooth rolling lands by filling in the deepest craters with soil from the side slopes and crater walls. These new soils would be less productive than the previous alluvial soils due to the lower soil organic carbon content, greater slope, and lack of topsoil and subsoil material in the root zone.

A depositional inventory and map at a fine resolution scale is needed to show key hydrogeological features such as drainage of land and fields, drainage ditches, road ditches and waterways to assess the extent of deposition and contamination of streams and lakes. The characterization and re-mapping of soils can increase the capacity of public (USACE) and private levee systems to not only address short-term structural repairs but also put in place strategic landscape level designs

that adapt to changing future uncertainties. Second, assessment of contamination effects on soil productivity and long-term agricultural production is central to understanding the impacts of flooding on agricultural soils. There is health concern related to any pollutants that might be in floodwaters such as untreated sewage from plants that were flooded or other chemicals picked up by floodwaters. When the organic and clay particles coating the plants and soils are dried in sunlight most pathogens are likely to be destroyed depending on concentration levels and sun exposure.

Tillage can be used to bury or mix potentially toxic coatings into the topsoil layer which will dilute most toxic chemicals. It is not known whether the soil organic carbon content of the alluvial soils would be increased because of sediment and exposure to carbon rich floodwater. It is anticipated that microbes will decompose the carbon deposited with the sediment or in the thin surface coating and release the carbon to the atmosphere as either carbon dioxide or methane gases depending on whether there are aerobic or anaerobic conditions at the time the microbes are active. Some types of management practices and crop selections are less vulnerable to saturated soils and moderate soil contamination than others. Access to an assessment report will help farmers, local NRCS (Natural Resource Conservation Service) technical staff, extension educators, and crop advisors in documenting crop losses, developing and implementing remedial strategies, and evaluating a variety of alternative options regarding future land use, crop rotation, seed selection, timing, tillage management and inputs necessary to assure profitability of future crops.

Lastly, a pattern of intensive resource use, human, equipment, energy, financial, and social, emerges from levee breach events and the reconstruction investments needed to repair levees, return the land to crop production, and create a resilient landscape that is less vulnerable to future flooding and levee breaching stress. Re-assessment of current levee locations and designs is recommended in response to expected future increase in extreme and highly variable weather pattern (flooding and drought) and changing climate conditions. Park *et al.* [11] assert that engineering risk analysis based on assumptions that future events are expected will miss the mark in being prepared for the next unpredictable catastrophe flooding event unless resilience analysis is part of the systems approach. They elaborate that resilience analysis demands continuous management and recognition there will always be unidentified or emergent factors that cannot be accounted for and calls for more flexible engineering designs to better respond to uncertain and unpredictable conditions. This suggests that 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 resilience within these landscapes. These wetlands mimic natural floodplain functions by increasing water storage capacity during flooding and reducing water pressure on levee systems thereby reducing social, biophysical and economic impacts of soil degradation and con-

tamination and improving the overall resilience of agricultural productivity in deltaic environments.

#### 4. Summary

Public and private levee systems may not be robust enough to address flooding risk to agriculture under changing climate conditions [13]. Of concern are levee protected riverine bottomlands with intensive agricultural uses and diminished wetland systems that give resilience to floodplain hydrologic functions. In the United States natural and induced levee breaching has caused soil damage, loss of agricultural productivity, and public tension among agricultural landowners, urban residents, and environmental interests. Risk management and adaptive capacity of this human natural system could be improved by assessments of: 1) Soil damage; 2) Stakeholder values, fears, and knowledge about the riverine bottomland agroecosystem. Levee protected agricultural lands are some of the most fertile and productive soils in the world. These lands which are part of the global food security network are highly vulnerable and at risk of riverine flooding and levee breaching under changing climatic conditions. While most types of riverine flooding are known risks with repetitive behaviors, a shifting climate can change the frequency, seasonality, and severity of flood events, often in random ways [14] [15]. The uncertainty and nonlinear second and third order effects of the global climate system can amplify or attenuate the non-uniform distribution of precipitation and threaten the integrity of dams, levees and other structures designed to protect land uses adjacent to rivers [16] and alter the resilience of these landscapes. More than 75% of the disasters that have occurred globally over the past decade have been triggered by climate and climate related hazards such as floods, storms and drought [17] [18].

In the United States (US) much of the 1993 flooding was associated with sand boils and structural failure of levees (rather than overtopping) due to prolonged high flood stages and unusually large runoff in systems that were cut off from historical flood plains [15]. Flooding of agricultural lands, particularly those adjacent to rivers and their alluvial plains, can have impacts and persistent effects on soil erosion and degradation, crop productivity, economic, social, and ecological conditions. The 2007 and 2014 Intergovernmental Panel on Climate Change (IPCC) Reports concluded that current water management practices may not be robust enough to cope with impacts of climate change and draw specific attention to flooding risk in agriculture and ecological systems [19] [20]. For example, the Mississippi River Basin which drains more than 41% of the continental US experienced major flooding and levee breaching in 1993 and 2011 with damage in the billions of dollars to levees, agriculture, livestock, fields, farm buildings and equipment [15] [16] [21]. Resilience in the context of disaster management is the capacity of the floodplain system to absorb disturbances such as flooding and still retain basic social, economic, and ecosystem functions [17] [22].

Park *et al.* [11] called for risk management engineering that moves beyond risk

minimization and strengthening physical infrastructures toward system resilience goals and strategies that provide information feedback loops to minimize the consequences of failure and increase the flexibility of engineered, natural, and social systems to respond to uncertain and unpredictable conditions. This suggests the need for new risk and resilience approaches to managing leveed agroecosystems that, in conjunction with reliance on structural solutions, embrace adaptive management strategies which assess: 1) Changing soil conditions and land uses from levee breaching; 2) Local and regional stakeholder values, fears, social, and economic conditions. These assessments can provide valuable feedback to improve capacity building and adaptive management that accomplish multifunctional goals.

In this paper riverine bottomland flooding and vulnerability to levee breaching in the US are discussed followed by a case study of southeast Missouri (Bootheel) leveed agricultural lands. Historical land use patterns of leveed lands and the Great Flood of 2011 on the Middle Mississippi River are used to illustrate the impacts of flooding and levee breaching on soil conditions and agricultural productivity as well as public tensions associated with recovery and reconstruction. We recommend that scientific assessment of soil damage and crop productivity, riverine ecosystems, and uncertainty in climate conditions be linked to diverse public values to improve decision making that deals with facts and values.

Every watershed on the Middle Mississippi River has to deal with significant flooding during the rainy season with or without levee breach issues. Knowledge gained from past episodic disasters can break down barriers to change and become a source of new information used to reframe future decisions as public agencies, private organizations and citizens work to prepare for future ecosystem disruptions [13]. Levees have been a valuable infrastructure in protecting the productivity of agriculture in riverine bottom lands, however they may be inadequate as the distribution, seasonality and intensity of precipitation patterns change.

Morton and Olson [13] called for the restoration of the large-river floodplains utilizing the natural ecosystem to mitigate flood hazard and risks associated with climate change. Wholly returning leveed river bottomlands to their original wetland state has political, social and economic barriers that make this change in land use highly unlikely under current conditions. However, as government agencies, technical advisors and society better understand the ecological functions of the riverine floodplain—the roles that hydrology, wetlands, and soils play in filtering, absorbing, and storing flood water—there may be an increased willingness to adapt and “live with floods” [15]. Social-ecological systems are dynamic and continually adapting (and mal-adapting) in unpredictable ways. While focusing on risks to levee design may meet goals of efficiency and temporarily hold equilibrium, additional agroecosystem strategies are needed to build resilience that balance social, economic, and ecosystem vulnerabilities. Taken together, assessments of stakeholder values, knowledge and willingness to adapt and assessments of changing soil conditions and other ecosystem functions are essential feedback in-

formation to the scientific analytics and deliberative processes necessary to guide planning and adaptive management for future uncertainties.

## 5. Conclusions

It is well recognized that managing river landscapes involves a great deal of engineering as well as the physical and natural sciences [1]. Often overlooked is the human factor—the patterns of civilization, the human and social decisions and actions that underlie the making of the natural environment to reflect human values and aspirations [1]. The Middle Mississippi 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 choose 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 to “win” their preferred project and the resources needed 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 to find shared solutions to common problems?

Social science [6] [15] [16] suggests four key elements are foundational to constructing a civic structure capable of realizing system level goals: 1) A common vision; 2) Iterative exchanges of knowledge and perspectives; 3) Public and private collaborative partnerships in the public interest; 4) Processes and mechanisms

that integrate and utilize scientific and non-scientific 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 land-owners 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 and Little River Drainage District in Missouri 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 [9]. Their steering committee represents a diversity of sectors including conservation, navigation, agriculture, flood control and risk reduction, industry, academic, ba-

sin 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.

Much can be learned by observing and studying the human and natural systems of river landscapes. I framed this Middle Mississippi River capstone article as a series of short case studies about leveed agricultural lands, river navigation, upland reservoirs, and landscape management of flood risks. Together, these stories reveal that change is the only certainty in river systems. Many factors influence and affect change. Olson and Morton [1] observed: “*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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### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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