Soil Degradation and Flooding Risk Decision Making in Leveed Agricultural Landscapes

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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 continually at risk of river flooding and levee breaching. Most types of river flooding have repetitive behaviors presenting known risks. However, highly variable weather and a shifting climate can change the frequency, seasonality, and severity of flood events, often in random ways, creating unpredictable risks [1, 2]. The uncertainty and nonlinear second and third order effects of the global climate system can amplify the nonuniform distribution of precipitation and threaten the integrity of dams, levees, and other structures designed to protect land uses adjacent to rivers [3].

More than 75% of the disasters that have occurred globally over the past decade have been triggered by weather- and climate-related hazards such as floods, storms, and drought. In the United States 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 floodplains [2, 4]. Flooding of agricultural lands, particularly those adjacent to rivers and alluvial river plains, can have high impact and persistent effects on soil erosion and degradation; crop productivity; and economic, social, and ecological conditions. The 2008 Intergovernmental Panel on Climate Change Report concluded that current water management practices may not be sufficient to cope with impacts of a changing climate and draws specific attention to flooding risk in agricultural and ecological systems. For example, the Mississippi River basin 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 [2, 3, 4].

A new generation of engineers is calling for risk management engineering that extends beyond risk minimization and strengthening of physical infrastructures [5]. They promote a system approach that uses information feedback loops to minimize the consequences of failure and increase the flexibility of engineered, natural, and social systems to better respond to unstable and unpredictable conditions. This kind of management integrates structural solutions with adaptive management strategies by continuous monitoring and assessments of land use changes, soil and water damages from flooding and levee breaching, economic and social conditions, and stakeholder perceptions and concerns. [5, 6]. These assessments provide valuable feedback that improves capacity to develop solutions that accomplish societal goals. In this chapter, river bottomland flooding and vulnerability to levee breaching in the United States are discussed using southeast Missouri (Bootheel) leveed agricultural lands (see chapters 10 through 13) for illustration. Historical land use patterns of leveed lands and the great flood of 2011 on the Mississippi River reveal the impacts of flooding and levee breaching on soil conditions and agricultural productivity as well as public tensions associated with recovery and reconstruction. The linking of scientific knowledge and social values and concerns is central to effectively managing leveed agricultural land under changing conditions to address risks and future uncertainty.

Leveed River Bottomlands and Levee Breaching

Leveed river bottomlands are designed to protect human populations and various land uses, including agriculture, from flooding. When a levee fails, the damage caused by floodwaters and contamination of water and land is significant [7]. Water-borne sediments often cover plants and soils and fill in road ditches, drainage ditches, and waterways, or re-enter water in rivers, streams, and lakes. Frequently crater lakes are created by floodwaters either topping or pouring through the levee breach, and substantive gullies develop [8]. These gullies and land scour areas can extend into the floodplain several miles beyond the breach into fields or along ridges. As the water slows, the coarse sediments, such as sand, are deposited first on the alluvial soils followed by silt and clay.

Sediment is the primary water pollutant on a mass basis, and the sediment often carries with it other nutrients and pollutants including pathogens, hydrocarbons, and pesticides. Once fields dry out, thin sediment deposits may be incorporated into the soil with tillage. The effects on soil productivity and crop production are thought to be minimal. However, thick sediment deposits, such as sand deltas, require piling up and removal to restore agricultural functionality. The land scouring and erosional processes remove topsoil and create eroded phases and depositional phases on a soil and sometimes subsoil. The result is a less productive soil, even if land is reshaped and reclaimed [9, 10]. In addition, the sediment can block highway ditches and drainage ditches. This makes it difficult to remove excess water from the poorly drained soils and return the land to agricultural production.

The soil types; hydrogeologic features; volume of flow; time of year; and agricultural use of fertilizers, pesticides, and other chemicals affect the extent of land scouring and sedimentation. These factors and upstream point sources such as sewage treatment plants, storm sewer drainage, and other urban land uses influence the fine-scale remediation needed. Floodwater can also damage surface and subsurface water and impact water tables within the watershed. The productivity of these soils, including their capacity to hold moisture under future drought conditions compared to the original soils, is not measured. Thus, effects of sediment deposition and land scouring on soil profiles and productivity are often unknown. This makes it difficult for agency technical staff, local leadership, and farmers to have sufficient information to effectively restore soil productivity and put in place strategies and infrastructure to prepare for future flood events.

Most research related to the impact of flooding on floodplain soils has focused on natural, seasonal flood events where the inundation and subsequent drainage of the land occurs as relatively slow, low-energy processes. In contrast, levee breaches result in a very fast, high-energy release of large quantities of water onto the floodplain. A closer examination of the New Madrid Floodway, Missouri, and the US Army Corps of Engineers (USACE) induced breaching during the 2011 Ohio and Mississippi rivers flood offers an opportunity to synthesize lessons learned about river flood conditions, impacts of levee breaching on agricultural lands, and the social tensions associated with managing leveed landscapes.

New Madrid Floodway, Missouri

Historical Land Uses

The New Madrid Floodway, located immediately southwest of the confluence of the Mississippi and the Ohio rivers at Cairo, Illinois (see map 10.1), at 279 feet above sea level, was designed by the USACE in the aftermath of the deadly 1927 flood. The original frontline levee, which forms the eastern boundary of the floodway, was intended to protect land uses within the floodway until the Mississippi River reached the 55-foot stage, at which time the floodwater could naturally overtop the frontline levee. The USACE obtained easements between 1928 and 1932 from the landowners giving the right to pass floodwater into and through the New Madrid Floodway. The Flood Control Act of 1965 authorized modification of the New Madrid Floodway opera-

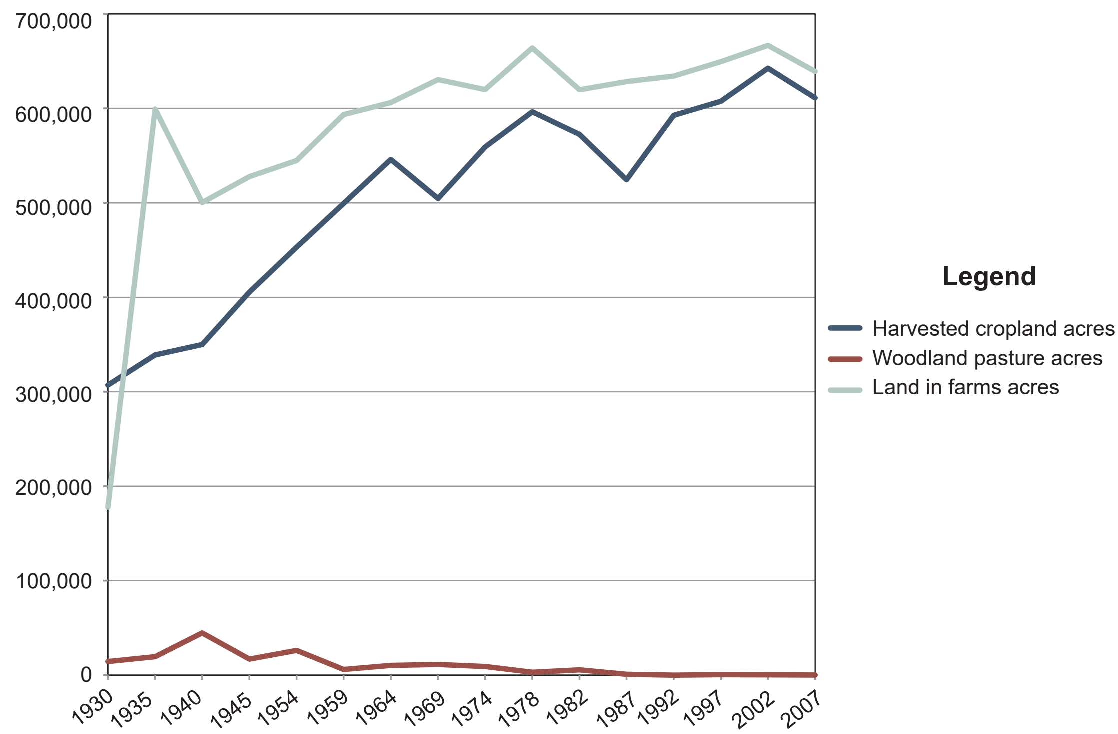

FIGURE 24.1 New Madrid and Mississippi counties' (Missouri) land uses from the USDA Census of Agriculture, 1930 to 2007.

tional plan; levees were raised and new easements were obtained. When the weather forecast predicts a 60-foot or higher Ohio River peak on the Cairo gage, the USACE must make a decision about the deliberate breaching of the New Madrid Floodway frontline levee fuse plugs to reduce pressure on the Cairo levee system and protect downstream cities and levees.

A look at the historical land use patterns of Mississippi River bottomlands places in perspective the implications and impacts of induced and natural breaching on levee-protected lands. Prior to settlement, the Missouri Bootheel contained more than half of all the state of Missouri's original 4.8 million acres of wetlands. Over time, almost all of these acres of wetlands and forested bottomlands were cleared, drained, and leveed for production agriculture, leaving 800,000 acres of wetlands in Missouri in 2013. The evolution of the New Madrid Floodway from forested bottomlands to productive agricultural lands is reflected in the land use change patterns between 1930 and 2007 of New Madrid and Mississippi counties (figure 24.1), a portion of which are levee-protected lands within the New Madrid Floodway. The US Census of Agriculture farmer-reported data for New Madrid and Mississippi counties show 6,510 farms with 338,988 acres in harvested cropland and 19,513 acres of woodland pasture in 1935. Seventy-two years later, in 2007, there were 578 farmers of record, harvested cropland acres had almost doubled to 610,979 acres, and woodland pasture substantively decreased to 139 acres. Although corn, soybean, wheat, cotton, and rice are the main cultivated crops in this region, an intensification of soybean production can be observed from 1945 to 2007 (figure 24.2). This likely reflects farmer adaptive management responses to seasonal wetness and flooding in these bottomlands as the soybean can be planted in early summer after saturated and flooded soils have drained.

Soil Functional Uses and Productivity

The characteristics of different soil series affect the functional uses and ecosystem services that the soil provides [11]. The flooding process can alter these functional uses when land is eroded by water and recreated as new soil where silt is deposited when sediment laden water slows down. Flooding can have beneficial effects: replenishing agricultural soils with new nutrients (when the water is not contaminated) and transporting sediment downstream to maintain delta and coastal areas [2]. However, flooding can also leave behind infertile sand and degraded soils, thus changing the soil functionality to a less than optimal state as soil organic matter is lost. Alterations in soil functionality can change its ability to sustain biological activity and productivity. Changes also affect how well soil regulates water, filters nutrients, buffers and detoxifies organic and inorganic materials, and stores and cycles nutrients. These soil activities are critical to the floodplain system. They affect not only future agricultural productivity but also riparian wetlands that are the hydrologic and biogeochemical buffers in the floodplain.

The types of vegetation present and the route floodwaters take can affect changes in soil characteristics and significantly influence the scouring and deposition of sediments during a flood event, especially when the floodwater carries a large amount of energy. For example, during the 2011 Mississippi River flood and induced breach of the Birds Point–New Madrid levee system, the field closest to the breach contained a healthy stand of winter wheat, and the soil was mostly protected from scouring. However, an adjacent recently tilled field further from the breach was severely impacted by scouring and loss of topsoil. There is a natural feedback cycle between vegetation and hydrology in floodplains. Flood impacts on the land are affected by the structure and composition of the vegetation. Vegetation contributes to hydraulic roughness and influences patterns of sediment deposition [12]. This cycle and the relationships among natural and planted vegetation can be disrupted by natural and human changes in river hydrology. Thus levee breaching and flooding can lead to land scouring, soil erosion, and deep gullies in agricultural lands.

Tensions among Competing Economic, Ecological, and Geographic Interests

Levee structures and the agroecosystems they protect are shaped by local landowners and regional organizations and agencies representing diverse land use priorities and expectations for river bottomlands. Social values, fears of flooding and loss of property and life, and the management decisions that reflect these concerns are not static. Experiences with minor and major flooding events often change perceptions. New science and technologies and better understanding of the multifunctional roles of river ecosystems also influence how the river and its landscape are viewed. The New Madrid Floodway watershed is probably the most litigated watershed in the Mississippi River valley. A 140-farmer lawsuit in federal court for soil damages sustained when the floodway was opened in 2011 continues (as of October of 2015) through the court system.

In recent history, there have been three other lawsuits: in 1983 a farmer filed suit to challenge the use of explosives when opening the floodway (Story vs. Walsh);

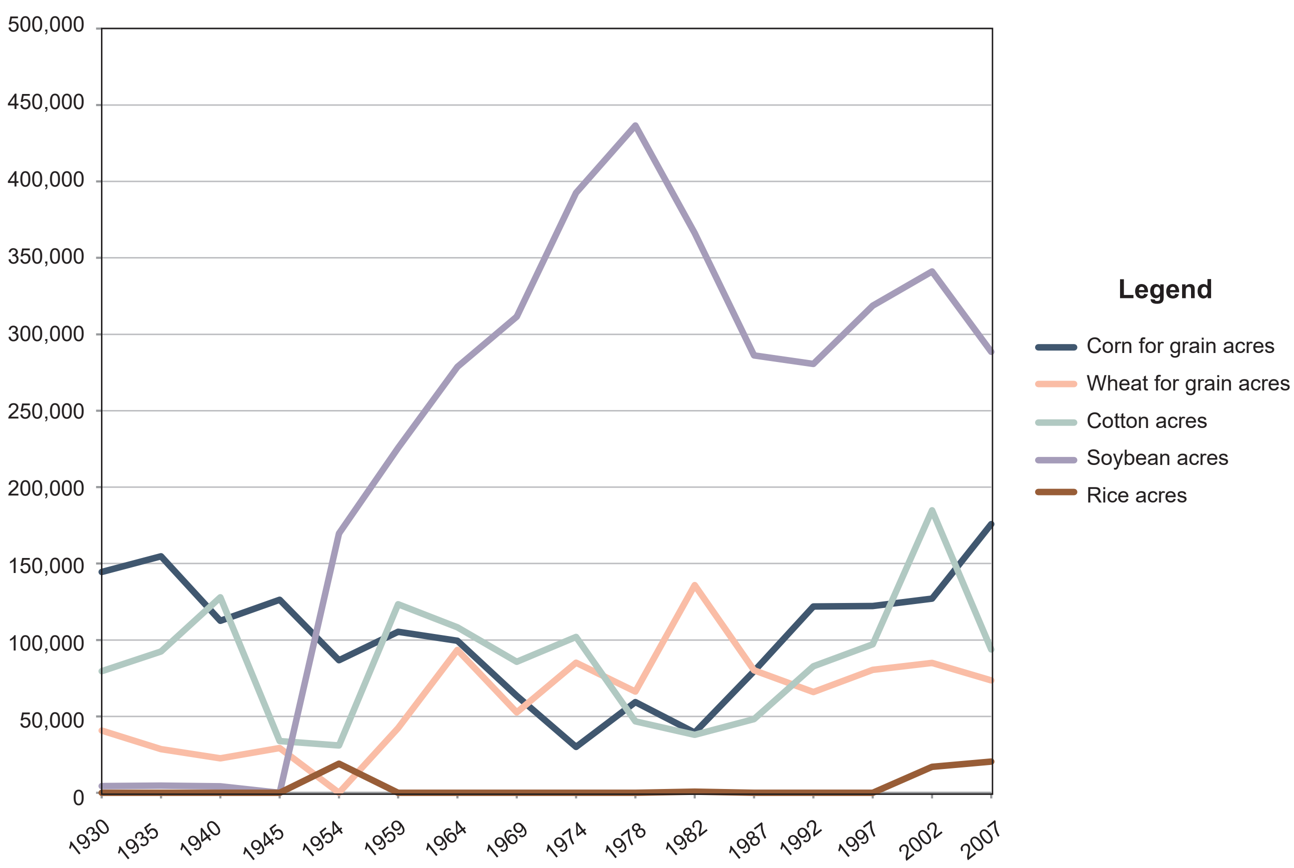

FIGURE 24.2 New Madrid and Mississippi counties' (Missouri) major crops from the USDA Census of Agriculture, 1930 to 2007.

in 2006 the Wildlife Defense Fund filed a suit to restore water flow to wetlands by removing a levee built in 2005 to close a gap northeast of the town of New Madrid (cost of $17 million to create and remove the levee); and in 2011 the Missouri Attorney General attempted unsuccessfully to block the opening of the floodway. This watershed has received the most federal funding ($50 million from 2011 to 2014 for repairs and restoration) ever spent on levee, floodway, and drainage projects in the Mississippi River valley, in addition to substantive state and local public and private dollars. These costs do not include the annual maintenance costs of the Mississippi River Commission and USACE since 1932. Congress is currently considering funding for a new $170 million proposal for the St. Johns Levee and Drainage District to close the gap again and build pump stations and more gates to create an outlet for the drainage district to the Mississippi River (see chapter 7).

Engaging the Public

Recent natural and human-made disasters like levee breaching accentuate the increasing social, economic, and environmental conflicts that surround leveed river bottomlands. In addition to the emergency and reconstruction efforts associated with lands flooded and levees breached, local stakeholders and regional and federal entities must plan forward to mitigate future flood disasters. The complexity of federal, regional, state, and local regulatory oversight and management responsibilities for the river, levee systems, and adjacent public and private land uses complicates decision making and effective governance. This forward planning takes strong leadership and extensive cooperative management effort at several scales that are not always understood or welcomed by people who have a stake in how the landscape is managed [3].

Public hearings held by the USACE in August of 2013 to discuss St. Johns Bayou–New Madrid Floodway proposals to reduce the number of days communities are isolated by floodwaters, reduce crop and noncrop agricultural damages, and reduce critical infrastructure damages to streets and roads illustrate the difficulty in finding consensus among competing sectorial and geographic interests. The overall goals of the USACE alternative mitigation proposals articulated well stakeholder shared concerns. However, strategies for achieving them revealed strident urban-rural, upriver-downriver, and agricultural-environmental divides, including differences in cultures, values, and locational impacts. The agricultural landowners of the floodway were particularly angered by outside environmentalist testimonies claiming that migratory bird populations and wetland habitats were of equal value to agricultural production uses. Upriver Cairo homeowners wanted reassurance that the floodway would continue to be used under future extreme events and were fearful intensified agricultural land use would make the decision politically difficult. These competing values and views were apparent in the USACE public hearing testimonies.

Floodway landowner:

> *I want to take a brief moment and talk about agricultural growth of this region...We have capitalized, well-educated farmers. This region could be the most productive agricultural region in North America, especially given what California is doing with the Central Valley. This region is prone to bring in more agribusinesses to relocate here...We now have thousands of acres of sweet potatoes grown in this region, thousands of acres of potatoes...almost a quarter million acres of rice...the river is the gateway to Asian markets.*

Cairo homeowner:

> *I am from Illinois, and there were some comments made here tonight about not blowing the levee. I want to say—blow the levee. The land was bought (easement) for that. This is the face that comes from a town that... was almost destroyed...when you start talking about moving in the new stuff, the building up of this area... that frightens us in Illinois, the more that moves in here (increased agricultural development), the harder it's going to be to get that levee blown. I want you to know...three foot of water in my home...day and night we didn't stop sandbagging.*

Despite tensions associated with stakeholder differences, participatory processes are valuable in providing a common platform for making information available to all sectors and encouraging community identification of the problems and shared responsibility for finding solutions [13]. Analytic deliberative processes that link scientific information to public discussions can ground contentious conversations in factual knowledge [14]. Although changes in values and shifts from self-interest to altruism are long-term processes, people can change beliefs because "we hold to norms that tell us beliefs should change with new evidence: a norm that comes from science" [14].

Hazard mitigation and regional planning must seek wide participation of those who have a stake in decisions. However, good decision making must be factually competent. Required public hearings are one way

FIGURE 24.3 Wetlands and ponds in the deep gullies of O'Bryan Ridge (October of 2013) replace a productive soybean field after the May of 2011 levee breach and flooding.

a democracy obtains information about stakeholder beliefs, concerns, and opinions but alone are insufficient in guiding effective management. Full consensus is difficult and often not achievable or even desirable as there is frequently a strong preference for self-interest, the status quo, and a lack of knowledge about the floodplain as an ecological system [3, 15]. Public deliberative processes provide space to communicate the (*a*) problem of uncertainty, (*b*) facts associated with managing river ecosystems under changing current and future conditions, and (*c*) diverse values and concerns of stakeholders.

Local public agencies and private stakeholders with intermediary land use and water management responsibilities (e.g., levee districts, planning commissions, and soil and water conservation districts) can be barriers or enablers in facilitating how scientific facts and social values are linked. These leaders are key conduits of information exchange among local landowners and residents; federal and state agencies; and nonlocal publics with specific, larger societal interests. They play central roles in assessing the social, economic, and biogeophysical situations after disaster events. They can communicate known science about soil, hydrology, wetlands, and agricultural landscapes, and propose a variety of solutions to reduce future vulnerability and risk. They can also facilitate trust among sectors and between citizens and government agencies so resources can be mobilized. Social distrust of government is a major barrier to developing resilient, diversified river landscapes with complementary wetland and agricultural uses [15]. Trust is essential if adaptive management policies are to effectively combine engineering solutions with resilience-based management that reduces risk and vulnerability of levee-protected agroecosystems.

Generating New Solutions

Purposeful stakeholder engagement not only offers an information forum but can also generate new solutions. One public testimony to the 2013 USACE mitigation proposal noted that the agency environmental report

> *...did not contain an agronomic section where these details would be discussed...the economic opportunity cost of not providing the option of using a corn–soybean; corn–soybean–soybean; or corn–wheat–soybean rotation should be factored...it would be reasonable to figure the cost of potential crop productivity losses from increased crop pests when a single crop is used over the years.*

Further the testimony asserted, "...this is an important oversight, as demonstrated in the report's economic section..." The economic report referenced notes, "key assumptions are missing," notably evidence of current agricultural production.

A main concern underlying this testimony is the need for data and assessments that can guide adaptive management in the context of reconstruction after flooding and the reevaluation of land uses for increased resilience to future disruptions. Adaptive management entails social, economic, and biogeophysical adjustments based on past events such as flooding disasters, or adjustments in anticipation of future hazards and risks. Planning that accomplishes adaptive management integrates engineering risk and broader landscape resilience approaches. This includes comprehensive assessments before and after flood events, such as assessment of soil characteristics and degradation, hydrology, wetland habitats, and social and economic conditions [5, 6, 16]. The 2011 flood event and the New Madrid Floodway levee breaching and reconstruction provide important lessons in developing public policies that are responsive to the complexity of the coupled human-natural system at local, regional, and national scales.

Managing land and living in a floodplain means farmers, residents, industries, and supporting institutions as well as public and private levee districts must always assume there will be another flood event. They need short- and long-term strategies as well as public policies to (*a*) sustain their systems of levees, (*b*) address breaching events and reclaim agricultural lands, and (*c*) put in place plans that anticipate future events. Levees are complex engineered systems linked to river systems, wetland and agricultural systems, and social systems. Due to incomplete knowledge of these dynamic systems and how they interact, future levee redesigns must not only account for risks to the engineered system but also risks and uncertainty associated with land use and social, economic, soil, and hydrologic conditions.

Soil Assessment

Resilience analysis and engineering is premised on the unknown risks that can't be planned for. Management focuses on preparing for emergent and unexpected events by continuously gathering new information and using these data as feedback loops to adjust as conditions change. In agricultural-leveed landscapes new information about soil damage and agronomic impacts from breaching and flooding is needed each time a levee fails. Soil condition assessments as part of the resilience analysis would offer (*a*) improved delineation of eroded and depositional soils associated with levee breaching, (*b*) better measurements of soil deposition and land scouring, and (*c*) finer resolution mapping of key hydrogeologic features. These assessments would increase the capacity of the USACE, local USDA Natural Resource Conservation Service technical specialists, Extension agronomists, soil and water conservation district commissioners, and levee district leadership to address short-term structural repairs. They would also enable strategic landscape level redesign to balance production agriculture and wetland ecosystem services needed to improve the resilience of the floodplain system.

New spatial technologies such as geographic information systems (GIS), light detection and ranging (LiDAR), and remote sensing are tools for assessing disasters and building a hazard information database to guide decision making for preparedness, response, and recovery. GIS utilizes spatially referenced data, integrating these data into electronic digital maps. Remote sensing data are obtained from sensors on fixed wing aircraft and satellite links and provide earth surface imagery. New unmanned aerial vehicles (UAV) offer huge potential for gathering site-specific and landscape-level data to better track real-time change. These technologies hold great potential to assess current conditions and develop models for scenarios to guide future flooding and levee breaching disaster preparedness and remediation.

However, these technologies are dependent upon accurate soil survey data obtained from field measurements. Many of the published US county soil survey maps are one-time surveys and are 1 to 30 years old. At best, they reflect eroded conditions, deposition, and degradation at the time the soil survey was made. Changes that have occurred from land use practices (e.g., cultivation of marginal lands, drainage of wetlands, or poor agricultural management practices) or from subsequent flood events are not reflected on the published soil maps. Levee breaching and flooding and their impacts on soil and soil productivity need to be documented in updated soil surveys. Restoration plans can be developed based on these updated soil surveys and would include locations of permanent soil productivity losses; damaged or abandoned levees; crater lakes, gullies, and thick sand deposits; sediment-filled drainage and road ditches; and land scouring. Soil degradation may be so severe in some locations, as in the case of the gully field on O'Bryan Ridge, that the land use has to change from agricultural use to wetlands (figure 24.3) with a loss in soil productivity and agricultural production (see chapter 13). Any flooding-related damages to the soils can result in changes in soil series on the maps, result in new reconstructed soils, or a change the erosion or depositional phases of existing soils. Thus, accurate soil surveys and maps are a critical basis for developing soil and water conservation plans.

Updating of the national soil survey after every levee breach is congruent with the Committee on Increasing National Resilience to Hazards and Disasters recommendations to establish a disaster-related database to better quantify risk models and structural vulnerability [17]. This recommendation could be implemented by an agreement between the USACE and the USDA Natural Resource Conservation Service to ensure a rapid federal response after levee breach and flooding. This could be part of the federal government's response to a disaster, along with emergency funds for restoration work including drainage ditch opening, levee repairs, crater lake filling, gully repairs, and sand deposit removal.

Assessments of Stakeholder Values, Perceptions, and Social and Economic Conditions

Adaptive management that includes deliberative processes beyond public hearings for gathering information about stakeholder concerns and social and economic conditions can increase decision making capacities. In managing the larger floodplain system, science and technologies must be linked to social values if social learning and behavior changes are to occur [14]. There are a variety of social science tools for assessing economic conditions, stakeholder values, willingness to participate in incentive programs, impacts of rules and regulation, perceptions of threats to physical safety, vulnerability of livelihoods to increased weather uncertainty, and evaluation of agency-proposed technical solutions [13]. For example, a 2013 survey of landowners [15] reported that program design and delivery of voluntary conservation programs influenced willingness to participate in adding biodiversity to land management plans. This kind of information could be particularly valuable in developing policies and programs that combine agricultural production with wetland management that reconnects the floodplain to the hydrology of the river.

Citizen assessments and participation in public decision making often reveal current and emerging divergent opinions that can lead to polarized positions as well as bring to light areas of agreement and common ground. Stakeholder consensus on levee and floodplain ecosystem management is highly unlikely in many instances. However, understanding the heterogeneity of fears and motivations for how land is managed acknowledges the variety of preferences, attitudes, and cultures and can lead to creative collaborative solutions and compromises. This information can help guide agency and public decision makers in negotiating solutions congruent with local values and increase policymakers' understanding of stakeholder fears and concerns associated with threats to safety and livelihoods as well as conflicting interests associated with restoration of river habitats and agricultural land uses.

Assessment tools such as surveys and listening sessions are particularly effective when findings are shared with stakeholders and presented in combination with biogeophysical and ecosystem data and the problems associated with managing the floodplain. Providing various stakeholders access to information including factual science about climate and weather patterns, river hydrology, soil and agronomic factors, levee structures, and bottomland ecosystems increases local knowledge and understanding of the landscape-level problem. Further, public forums offer stakeholders opportunities to contribute their experiential knowledge and engage in dialogues about what the problem is, impacts on their livelihoods, and strategies for addressing and adapting to changing conditions.

Stakeholder assessment and engagement can encompass use of websites and social media to make factual, accurate data accessible and gather feedback in a timely manner. However, this forum of exchange is not a substitute for creating and strengthening local and regional relationships and networks. Workshops, public meetings, goal-oriented committees, and public spaces for informal discussions can build trust; offer venues for exploring and negotiating solutions among divergent, competing values and interests; and meet multifunctional goals.

Focus on Flooding Solutions

Every watershed on the Mississippi and Ohio rivers has to deal with potential 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 disruptions [18]. Levees serve as valuable infrastructure in protecting the productivity of agricultural bottomlands. However, they may be inadequate if the distribution, seasonality, and intensity of precipitation patterns change. Restoration of large-river floodplains utilizing the natural ecosystem to mitigate flood hazard and risks associated with extreme precipitation events and changing climate is part of the solution [19]. Returning all leveed river bottomlands to their original wetland state has political, social, and economic barriers that make this change in land use highly unlikely and, in many cases, undesirable under current conditions. However, as government agencies, technical advisors, and society better understand the ecological functions of the river floodplain and the roles that hydrology, wetlands, and soils play in filtering, absorbing, and storing floodwater, there may be an increased willingness to adapt and live with floods. Social-ecological systems are dynamic and continually adapting (and mal-adapting) in unpredictable ways. While focus on risks to levee design may meet goals of efficiency and temporarily hold equilibrium, additional agroecosystem strategies that balance social, economic, and ecosystem vulnerabilities are needed to build resilience. Taken together, assessments of stakeholder values, knowledge, and willingness to adapt and assessments of changing soil conditions and other ecosystem functions are essential feedback information to the scientific analytics and deliberative processes necessary to guide planning and adaptive management for future uncertainties.

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