Agricultural Lands: Flooding and Levee Breaches

Kenneth R. Olson
Department of Natural Resources and Environmental Sciences, University of Illinois at Urbana-Champaign, Urbana, Illinois, U.S.A.

Lois Wright Morton
Department of Sociology, College of Agriculture and Life Sciences, Iowa State University, Ames, Iowa, U.S.A.

Abstract
Whenever levees on rivers are breached, there are soil and crop damages in the flooded bottomland areas that impact agricultural management capacities and crop productivity. Earthen levees and floodwalls can be undermined by sand boils, fail after weeks of high floodwater pressure and soil saturation, or even be topped. When a levee fails, there is often a crater lake created adjacent to the levee breach with gullies and land scouring extending into the previously protected lands. As the water spreads out and slows down, sand and sediments are deposited on the bottomlands and in road and drainage ditches. Floodwaters may drown crops and coat the entire flooded land surface with sediments containing a variety of pollutants, nutrients, and contaminants. Restoration of craters, gullies, land-scoured areas, and contaminated sediment depositional sites is necessary if agricultural lands are to be returned to some level of productivity.

INTRODUCTION

Alluvial soils are developed from fine-textured clay and silt sediments deposited in floodplains when rivers overflow their natural banks and flood into adjacent bottomlands. These water-saturated lands experience annual flooding for many months each year as the river levels vary with local and upstream precipitation and snowmelt. Fast moving floodwaters can also transport and deposit sand and gravel onto alluvial bottomlands. When these lands are drained and leveed to protect from river flooding, they are some of the most fertile and productive agricultural soils in the world. Whenever levees on rivers are breached, there are soil and crop damages in the flooded bottomland areas that impact agricultural management capacities and crop productivity. Earthen levees and floodwalls can be undermined by sand boils, fail after weeks of high floodwater pressure and soil saturation, or even be topped. When a levee fails, there is often a crater lake created adjacent to the levee breach with gullies and land scouring extending into the previously protected lands. As the water spreads out and slows down, sand and sediments are deposited on the bottomlands and in road and drainage ditches. Floodwaters may drown crops and coat the entire flooded land surface with sediments containing a variety of pollutants, nutrients, and contaminants. Restoration of craters, gullies, land-scoured areas, and contaminated sediment depositional sites is necessary if agricultural lands are to be returned to some level of productivity.

River Bottomlands, Agriculture, and Levees

In the United States, the Mississippi River and tributaries drain 41% of the continental land mass including millions of hectares of agricultural lands protected by thousands of kilometers of earthen levees and floodwalls. By 1926, an extensive system of private and public levees along the Mississippi River was engineered to secure agricultural lands and river cities against flooding[1] from the confluence of the Ohio and Mississippi rivers at Cairo, Illinois, all the way south to the Gulf of Mexico. The U.S. Army Corps of Engineers (USACE) and local levee districts continue to actively manage river levels to maintain navigation and protect against flooding. Prior to the construction of these levees, most river bottomlands experienced crop loss every time the river flooded, but the flooding caused little if any soil damage. Although these massive fortress-like structures seem impermeable, levees do fail for a variety of reasons and allow floodwater to flow through breaches with an intensity that can do substantive damage to agricultural crops. Not only does the crop drown if flooded during

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growing season, but considerable soil damage can also occur as a result of the levee breach and lead to the creation of crater lakes, gullies that extend into agricultural lands, land scouring, and sand and sediment deposition on bottomlands as well as drainage and road ditches. Further, as these fast moving waters slow down, the drowned crop and land surface are coated with silt, clay, organic matter, and other chemicals that the water carried. This flooding of crops and soils and the maintenance, repair, and strengthening of degraded levees cost millions of private and public dollars after every levee breach.

Changes in climate,[2] such as shifts in the long-term seasonality and frequency of extreme weather events, can result in record flooding and droughts and increase the vulnerability and risks associated with managing levee-protected agricultural lands. To understand the impacts of natural and induced levee breaching during high water and flood events, the levee system, the processes and mechanisms by which land scouring and sediment deposition occur, and the remedial activities that are used to repair and guard against levee breaching are discussed in the following sections.

Earthen Levees and Floodwalls

The levee is a massive earthworks designed to contain and channelize the river at flood stage and protect agriculture and other land uses against flooding. It has a flat crown with 3:1 sloped sides. The texture of the materials used in earthen levee construction can vary from silty clay to sandy. Grasses with thick dense roots are planted on the levee to hold the soil in place and reduce the erosive effect of water. Breaks in the levee, called breaches, can occur when a portion of the levee is eroded or breaks from a subsurface weakness. The higher the levee, the greater the force of the river on the protected land when a breach occurs; thus, a levee as high as a three- or four-story building can explode with the same power and suddenness of a dam bursting. Silty clay levees with a sand core can be affected by vegetation and animal burrowing, which in turn influence the susceptibility of the levee to erode and naturally breach. However, the greatest danger to levee failure is constant water pressure against the levee.[1,3] The weight of the river can push water underneath the levee and create sand boils that undermine the strength of the levee and its capacity to hold back water. Another type of levee is a floodwall constructed of concrete. These are often built in urban areas at the most erosive points in the river, usually the bend where strong currents and constant pressure of flowing water can erode an earthen levee. Floodwalls may also replace earthen levees when a large quantity of desired soil material is not available or is too costly to transport.

Levee Saturation and Topping

The water-holding capacities of the soil in earthen levees affect its strength to withstand the pressure of the river. During record flooding, the levee can be saturated for a prolonged period and fail, or the floodwater can be higher than the levee and top (run over) the levee crest (Fig. 1). When floodwater starts over the top of the levee, it can cut an erosion channel into and through the levee. Once the floodwater flows over or through a break in the levee, the

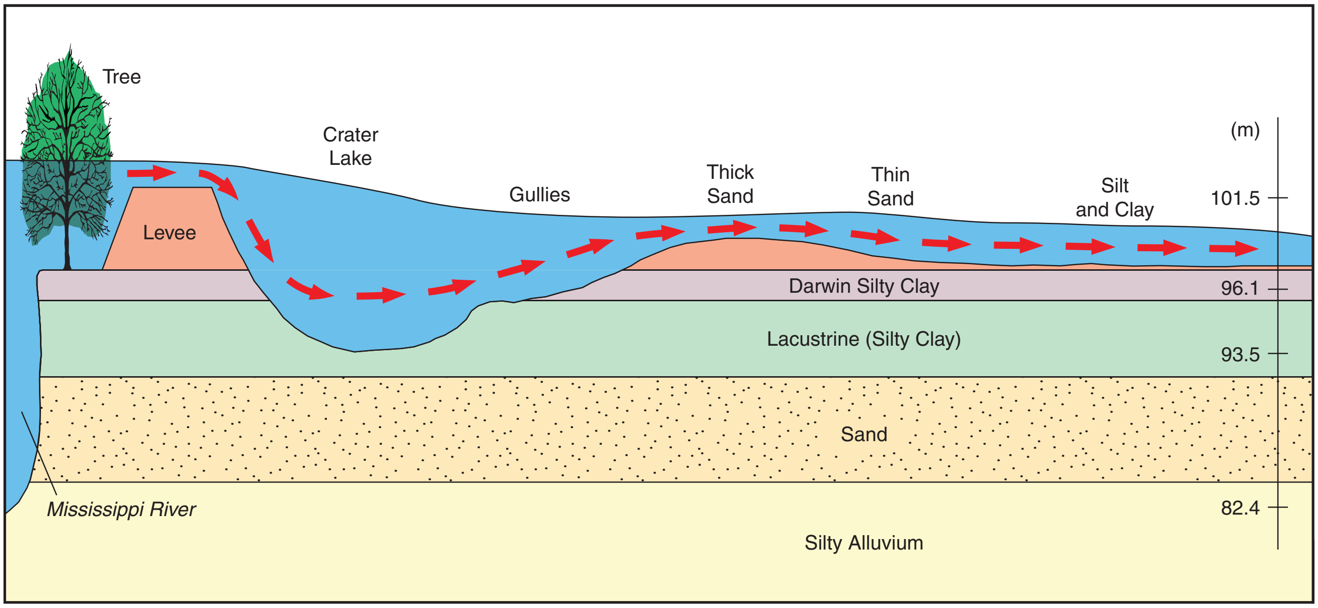

Fig. 1 Earthen levee topped by floodwaters resulting in a crater lake.
Source: Reprinted with permission from Olson & Morton.[5]

river water drops with great force and cuts a crater lake on the inside of the levee. As more water flows through the eroding crack, the floodwaters' speed increases and widens the breach by removing sections of the adjacent levee.[4] The breach can end up at 100 m or more in width and result in a deep crater lake.

Sand Boils

When floodwaters put significant pressure on floodwalls and levee systems, seepage and sand boils can occur, especially if there are sandy soils underneath the floodwall (Fig. 2) or earthen levee.[3] Sand boils, including a mega sand boil, occur when the river is at or above flood stage. The bottomland inside the levee acts like an empty sunken basin with the higher floodwater outside the basin creating a hydraulic gradient (Fig. 2). As the water seeks to equalize the pressure on both sides of the levee, a stream of water (called piping) can force its way through even a tiny opening in the riverside of the levee or floodwall.[4] Once the water is piped through the soil into the basin, the pressure is released and water shoots up through the porous earth or sand creating a churning or boiling action from which the sand boil is derived.[6]

Uncontrolled seepage, a major cause of levee failure, creates instability when high water pressure and soil saturation cause the earth materials to lose their strength. Most small sand boils are treated with a 1.5-m-high sandbag ring and filled with water.[4] The sandbag dike is normally a temporary measure to increase the depth and weight of water over the sand boil in order to decrease the hydraulic gradient across the seepage path and reduce the potential for erosion of earth materials along the piping path.[6] However, a sand boil can start small and quickly turn into a high-energy sand boil (Fig. 2). In a few hours, it can enlarge dramatically from a few centimeters to 0.6 m in diameter. In the case of a mega sand boil, the crew often has to construct a 15-m ring berm to a height of 2 m or more. When the counterweight of water alone is insufficient to control a mega

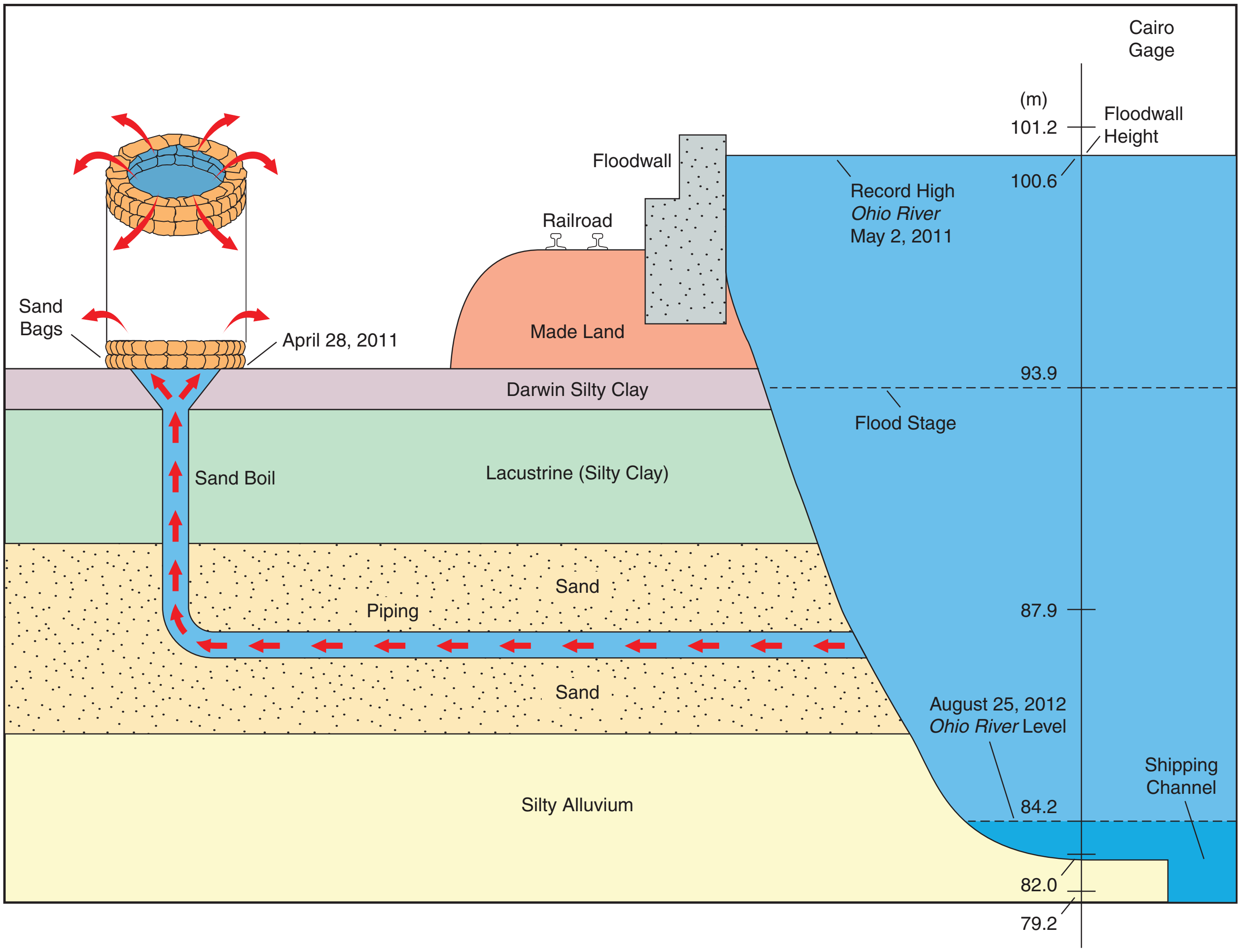

Fig. 2 Anatomy of a sand boil.
Source: Reprinted with permission from Morton & Olson.[7]

Fig. 3 Crater lake extending through 100-m levee breach.

sand boil, it is covered with a few meters of fly ash cinders or other available materials. The treatment of a mega sand boil can require big earth moving equipment such as bulldozers, backhoes, loaders, excavators, and dump trucks and a large crew to contain the mega sand boil and keep watch until the flood stage recedes.

Crater Lakes, Adjacent Gullies, and Thick Sand Deposits

As the floodwater tops or breaks through an earthen levee, it often drops many meters to the bottomland inside the levee and causes deep erosion of the soil and underlying geological parent material (Fig. 1). Most crater lakes (Fig. 3) are several meters deep.[3] As the floodwater flows rapidly into the previously protected bottomland, gullies originating adjacent to the crater lake are cut into the soil and can extend 10–100 m beyond. Geologic materials, soil, sand bars, and sediment carried down river and from the degraded earthen levee are deposited in the bottomland after the floodwaters slow down (Fig. 1).[3] The thick sand can be deposited on agricultural crops (Fig. 4) and other vegetation in the land surface as well as in drainage and road ditches.

Fig. 4 Sand delta covering corn field with tree residue from between river and levee.

Fig. 5 Gully fields on O'Bryan Ridge with levee in background.

Land Scouring and Gully Fields

After a levee breach occurs and the fast current of the water has created crater lakes, extended gullies into the bottomland (Fig. 5), and scoured the land surface, the speed of the advancing floodwater begins to slow and deposit sand particles on the bottomland in large sand deltas. As the floodwaters continue to slow, the silts drop and then the clay and organic particles settle out and coat plant residues and the land surface.[8,9] Significant land scouring can result in many hundreds of hectares of land losing centimeters of topsoil after each levee breach.

Levee-protected bottomlands normally have very little slope and are almost flat but can contain higher natural levees formed from old oxbows cut off from the river (Fig. 6). An oxbow is the wide curve portion of a meandering river channel. The floodwaters will pond in front of these meander scars or natural levees. When water flows over a natural levee ridge and drops down to another alluvial bottom, it concentrates and creates an eroded channel or waterway. This erosion process is called hydraulic jumping. As high-energy floodwater flows into the newly created waterway, it can cut into the ridge and carve additional new channels and gullies.

These deeply eroded soils or gully fields (Fig. 8) are extremely difficult and costly to reclaim.[8] Often bulldozers are used to push in the tops of the vertical gully walls to fill in the bottom and then grade the side slopes. The pushing of topsoil into the gullies puts the soil material on slopes that are highly erodible, and the exposed subsoil and parent material of the scrapped areas lower the productivity of the original soils. Topsoil must be hauled in to raise the soil organic carbon content of the soil if the land is to be returned to the previous level of agricultural productivity. Terracing is another option for reshaping the side slopes above the gully

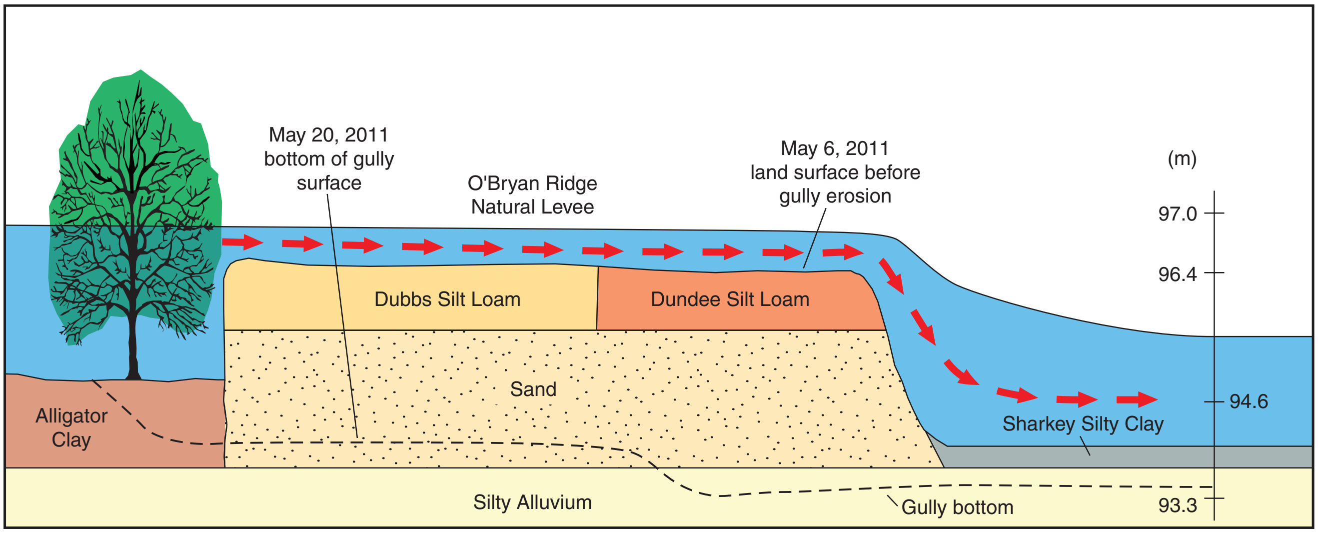

Fig. 6 Land scouring and gully formation when floodwaters flow over a natural levee ridge.

bottom. This approach will still result in the loss of long-term soil productivity and crop yields because the newly created soils will be less productive than the original soils as a result of mixing topsoil with parent material low in soil organic carbon. Reclamation efforts to restore these land-scoured ridges and gully fields can cost hundreds of thousands of dollars and are likely to still result in lowered soil productivity and crop yields when compared to original crop yields. When gully fields are created by levee breaching, the land use may change. Gullies that are not reclaimed will collect water and become wetlands. This loss of agricultural land to ponds and wetlands results in a net loss of agricultural productivity in the region.

Effect of Growing Crops and Residue on Erosion and Deposition

Crops grown in the Mississippi and Ohio River bottomlands are primarily wheat, corn, soybean, and forages. Depending on the time of year, the land cover may include these crops in various stages of growth or only plant residues remaining from the previous year's crop such as soybean stubble, corn stalks, and wheat stubble. When spring floods occur, winter wheat and forages are growing and are likely to drown. However, these fully developed plants can hold the soil in place and prevent the land scouring. Sediment carried by floodwaters is caught by the wheat and forage vegetation and deposited on the crop. If the levee breaching and flooding occur in the spring before corn and soybeans are planted, only previous crop plant residues are protecting the bottomland soils. These plant residues are often picked up and carried along by floodwaters and lose their protective capacity to prevent land scouring. When the flooding and levee breaching occur later in the growing season, the soybean and corn plants help slow the speed of the floodwaters and anchor the soil. After the floodwaters recede and the land drains, the soil can either be dried and planted or be left idle but tilled to eventually mix in the sediments to help dry out the fields depending on the timing of the flooding. Thin layers of silt and clay deposits can be treated by sunlight, drying, and tillage to incorporate into the plow layer. Tillage equipment, such as chisel plows and moldboard plows, can be used on the areas with thin sand deposits (<15 cm) in an attempt to mix the sand into the underlying bottomland with silty and clayey topsoil.

Crop damages depend on the type of crops commonly grown in the area and the timing of the levee breach and subsequent flooding. If flooding occurs in the growing season of a crop and the plants are under floodwater for 24–36 hours, the submerged crop will drown and can result in a total crop failure for that year. If flooded early in the growing season, the crop can be replanted but usually results in lower yields. Crop insurance can provide replacement for a portion of the income for farmers who have purchased it.[10,11]

Sediment Deposition in Road and Drainage Ditches

After a levee breach and flood event, road and drainage ditches in the area are filled with sediments and sand, sometimes as much as 1–2 m deep. Excavators are usually brought in by either the county or drainage districts or Natural Resources Conservation Service to remove debris and sediment that block drainageways and ditches to speed up the drainage process and to accelerate the drying out of low lying areas.[8,9] The sediment in private drainageways of most qualified landowners can sometimes be partially financed by the U.S. Department of Agriculture Emergency Services Agency's Conservation program. The local drainage district often provides additional matching funds for these projects.

Levee Repair, Sand Delta Removal, and Crater Lake Filling

If the funds are available, the USACE or the farmer levee and drainage districts usually begin reconstructing levees immediately after the floodwaters have drained. Sometimes, the levee is repaired in stages if the funds are insufficient for the entire reconstruction of the levee. Restoration and repair of the levee to the original height or higher is usually a concern of the landowners flooded by the levee breach.[9] The sand deposits are often collected and used to fill in the crater lake and then topsoil is trucked in and spread over the crater lake to restore the previous land use. The thick deltaic sand deposits can be 3–20 ha in size and between 0.1 and 1 m deep. Both the crater lakes and the thick sand deposits can result in a permanent loss of agricultural productivity[2,11] if they are not filled in or removed. The transported topsoil may come from other levees on smaller tributaries and drainage ditches or other adjacent soil deposits. The reconstructed soil profile will still be less productive than the original soils.

Damage to Farm Building and Homes

When a levee breach occurs, there is always the risk that lives and property may be lost or seriously harmed.[1] When a levee breach is eminent, the U.S. National Guard usually sweep the area to make sure the people living and working in levee-protected bottomlands are evacuated. There is also a high risk of damage to the homes, barns, and other structures on these flooded bottomlands.[12] Buildings can be impacted by the force of the flowing floodwater and become fully or partially submerged in the floodwater. Water pressure can result in the loss of the lower half of entire walls, damage wooden floors, or destroy structures completely. In addition, farm structures (sheds, barns, and grain bins) can be damaged, and depending on insurance coverage, only a few of these structures may be repaired.

Protected and Unprotected Agricultural Lands

River bottomland areas that are not protected by levees usually receive a thin layer of silt, clay, and organic matter during flood events. The crop is lost if flooding occurs in the growing season, but soils do not usually suffer permanent damage.[13] This is not the case where levees fail. Levees can fail as a result of a sand boil or by levee topping. Blowout holes or craters can be created between 1 and 10 ha in size and can hold water. Fast-flowing water can remove hundreds of meters of levee embankments and can erode thousands of cubic meters of soils and underlying outwash parent material to depths of many meters below the base of the earthen levee when the levee breaks.[4] The force of the rushing water can uproot trees growing between the river and the levee and deposit them, as residue, on the previously protected floodplain. Deep gullies can extend a few hundred meters into the bottomland, and hundreds of mature trees can be transported hundreds to thousands of meters. Deltaic sand deposits up to 1 m thick cover many hectares on the floodplain at each breach site with additional hectares covered with a thin layer of sand. The remaining hundreds of hectares of previously protected floodplain soils receive a thin coating of silt and clay and can remain under floodwaters long enough to drown the year's crop if it was planted and not already removed by the wall of advancing floodwater. After a few weeks, the floodwater usually drains from the bottomland and back into the river or slowly evaporates and infiltrates bottomland soils sufficiently for the local landowners to begin the task of moving the trees from near the blowout holes and floodplain and begin filling in the craters and gullies.[4]

CONCLUSION

Climate change will amplify the risks associated with snowmelt, rainfall, runoff patterns, and river flooding. As the odds for certain types of weather extremes increase in a warming climate, farmers, rural residents, and supporting institutions as well as public and private levee districts will need short- and long-term strategies to sustain their system of levees, address breaching events and reclamation of agricultural lands, and put in place adaptive management plans that anticipate events. Levees are complex engineered systems coupled with natural and social systems. Levee redesigns must account for not only the risks to the engineered system but how to make the social, economic, and environmental systems more resilient. One need is to better understand how the soils are affected by flooding and levee breaching and their capacities to support to agricultural productivity.

The following three recommendations are offered to provide valuable data in assessing soil degradation and to guide restoration in making levee-protected agricultural bottomlands more resilient: 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; and 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.

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