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Soil and Crop Damages as a Result of Levee Breaches on Ohio and Mississippi Rivers

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Abstract: Whenever levees on the Ohio or Mississippi rivers are breached, there are soil damages in the flooded areas that impact agricultural management capacities and crop productivity. 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 improve 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.

Key words: Flooding, levee breaches, crop loss, erosion, gullies, soil contamination.

1. Introduction

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 (US Army Corps of Engineers)) 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 [1-8]. 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 [9, 10]. 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 Mississippi rivers have resulted in short-term and long-term soil contamination and agricultural crop damages. 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

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substantively 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. Three case studies in the Ohio and Mississippi river basins 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 damages 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.

2. Results and Discussion

Leveed river bottomlands are designed to protect human populations and various land uses including agriculture from flooding. When a levee fails the damage and contamination of land is significant. 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. Sediment is eroded material that originates from weathered and eroded rocks and decomposing plants and animals suspended, transported and deposited by water. Sediments become contaminated when pollutants such as pesticides, fertilizers and industrial chemicals physically or chemically attach to the loose particles of sand, clay and silt. When sediment-laden flood waters recede, they often leave behind contaminated sediments, covering agriculturally productive soils and exposing crops to contamination as they take up nutrients from deposited materials. Sediment is the number one 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 are often incorporated into the soil with tillage and the effects on soil productivity and crop production are thought to be minimal. Thick sediment deposits such as sand deltas require piling up and removal of sand to restore functionality but the productivity of these soils compared to their original soils is not known.

In addition to contaminated sediment deposits, levee breaches also can lead to significant soil erosion and degradation including crater lakes and gullies created by floodwaters either topping or pouring through the levee breach. Gullies and land scour areas can extend many kilometers from the breach into fields or over ridges. As the water slows down the coarse sediments such as sand are deposited first on the alluvial soils followed by silt and clay with organic contaminates, pollutants and pathogens. This can result in many hectares of land being covered with 15 cm to 150 cm of sand in the form of a deltaic deposit which can become a sand dune if not removed. The silts and clays are carried further into the bottomlands and end up coating the soils and plants with contaminants. The texture (amount of sand, silt and clay) of the sediments will affect the retention or leaching of nutrients, pollutants, and contaminants. Both the land scouring and erosion process including gullies will remove topsoil, create eroded phases of depositional phases of a soil, and sometimes remove the subsoil, and in all cases result in less productive soils even if land is re-shaped and reclaimed [11]. Next, three case studies (Fig. 1), two natural levee breaches and the third, an induced breach, are presented to illustrate their impacts on soil contamination, degradation and damages to agricultural productivity.

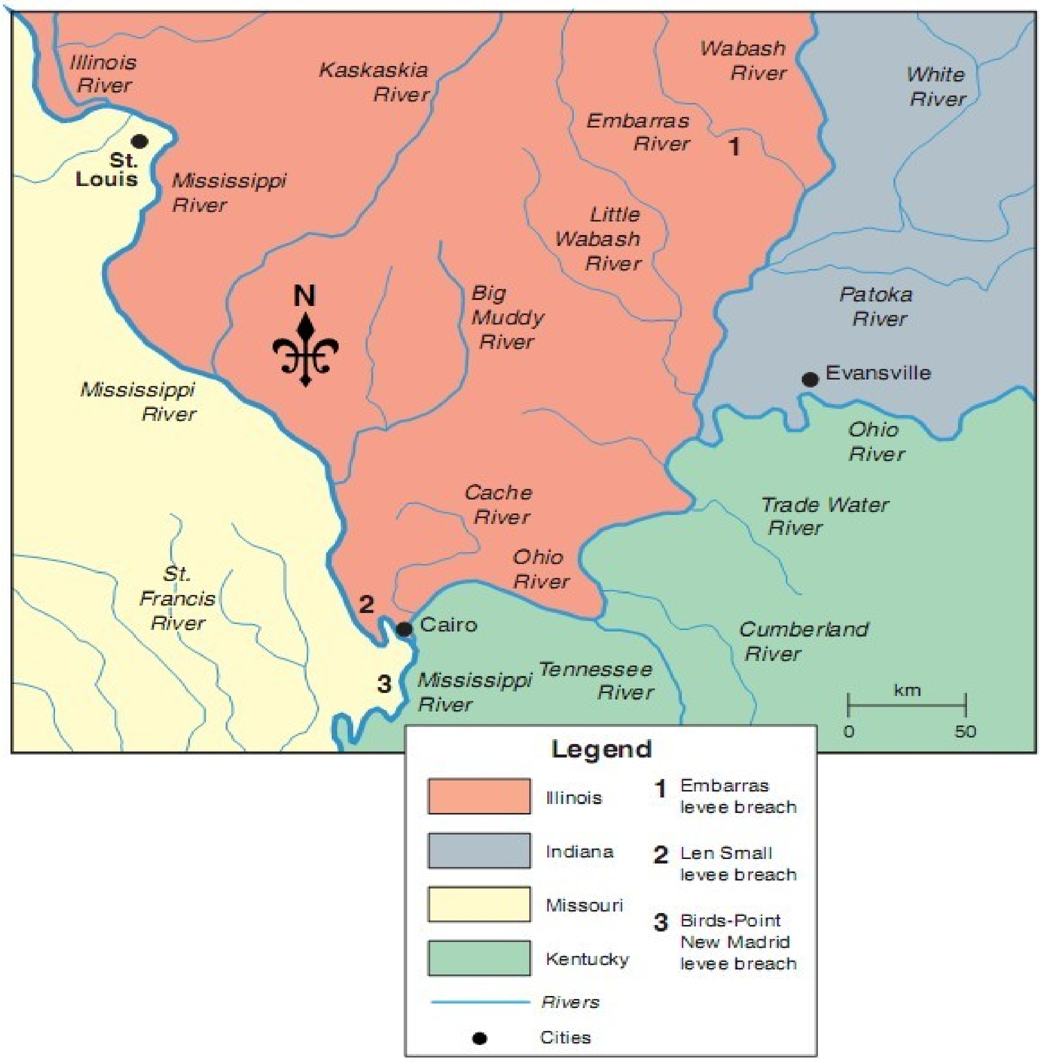

Fig. 1 Major rivers in southern Illinois and adjacent areas in Missouri, Kentucky and Indiana.

2.1 Case Study 1: Impacts of 2008 Flooding on Agricultural Lands in Illinois, Missouri and Indiana

The 2008 spring rains in Illinois, Missouri and Indiana delayed planting more than 3 weeks, drowned corn and soybean plants and resulted in significant re-planting. From May 30, 2008 to June 12, 2008, the previously saturated soils could not retain any more rainfall and the wetlands, potholes and depressions in the upland landscape filled with water and then began to runoff through waterways and into small streams. As much as 30% of the upland soils in south central Illinois, northern Missouri, and southern Indiana were affected by ponding (Fig. 2). Approximately, 1/3 of that ponded acreage was not re-planted in 2008. As overland flow started to occur so did sheet, rill and gully erosion. Where significant topsoil losses occur, soils can eventually shift intoanerosion phase change. Any soil erosion phase change from slightly to moderately or severely eroded can reduce the crop yield potential from 0.2 to 0.6 Mt/ha depending on whether the soils have favorable or unfavorable subsoil for rooting [12]. One year's erosion events do not change the erosion phase of the soil unless gullying occurs. However, the 2008 soil loss, when added to the soil loss from erosion in previous years, could eventually result in a soil erosion phase change.

During May 30 to June 12 period much of southern Indiana and south central Illinois received 20 cm to 30 cm of rain with little being stored in the soil. This resulted in local flooding with levees breaking in mid-June on the Embarras, White and Wabash rivers which drain into the Ohio River. Thousands of hectares of agricultural lands were impacted. Much of the

Fig. 2 Effects of ponding and flooding on corn plant populations.

2008 corn crop planted by June 8, 2008 on floodplain soils was lost due to flooding and many areas did not dry out sufficiently for crop planting until after July 15, 2008 making it too late to re-plant. In these areas the 2008 crop loss was total.

The areas that were not protected by levees and flooded only received a thin layer of silt and clay. Floodwaters on floodplains without levees resulted in 100% 2008 crop loss but soils did not suffer permanent damage. These soils received thin silt, sand or clay deposition which could be mixed with tillage equipment into the topsoil prior to planting the 2009 crops. This was not the case where levees failed (Fig. 3). Water removed a hundred meters of the levee embankments, eroded thousands of cubic meters of soils and underlying outwash parent material to depths of 3 m to 6 m below the base of the earthen levee when the levees broke. The force of the rushing water uprooted trees growing between the river and the levee prior to the break and deposited them on the previously protected floodplain. The 2008 crop on the floodplain soils behind the broken levees was a total loss.

This situation happened at two levee breaks southeast of Sainte Marie, IL. About 90 m of levee was lost at each break. Blow-out holes or craters were created that were 0.5 ha to 2 ha in size and held water (Fig. 4). Two to three meter deep gullies extended a few hundred meters into the previously protected floodplain and hundreds of 20-25 m high trees were transported hundreds to thousands of meters onto the now unprotected floodplain. Deltaic sand deposits up to 0.6 m thick covered 25 ha or more on the floodplain at each site (Fig. 5) with an additional 80 ha covered with a few centimeters of sand (Fig. 6). The remaining

Fig. 3 Levee breach on Embarras River.

Fig. 4 Crater lake adjacent to Embarras River and levee being filled in with sand.

Fig. 5 Embarras River (Illinois) breach and sand deposits in corn field.

Fig. 6 Sand being piled up and removed from bottomlands (Illinois).

hundreds or thousands of hectares of previously protected floodplain soils received a thin coating of silt and clay and remained under floodwaters long enough to drown out the year's crop. The road and drainage ditches were also filled with sand more than a 1.6 km from the levee break. By June 23, 2008 the water had drained from the floodplains and back into the Embarras River sufficiently for the local farmers to hire contractors with bulldozers, pans, graders, back hoes and buckets to begin the task of moving the trees from near the blow-out holes and floodplain and to begin filling in the craters and gullies.

Water storage structures, such as retention ponds, filled quickly with water and in some cases were covered by floodwaters. Risers and tile outlets were often insufficient to drain crop areas within 24 h or 48 h resulting in significant numbers of corn and soybean plants lost. Bottomlands, with levees that were not breached, had little 2008 crop lost except where tributary streams ponded water behind the levees. However, floodplains with levees that broke lost both the 2008 crops and agricultural land.

Why were Illinois, Missouri and Indiana vulnerable to flooding in 2008? The crop rotation in Illinois, Missouri, and Indiana is up to 90% corn and soybeans with limited acreage in small grains and forages. Further, urban and highway development in floodplains within the Mississippi, Missouri and Ohio river watersheds contributed to flooding problems. Drainage systems in the upland designed to remove excess water to open outlets in 24 h reduced crop plant loss but contributed to higher flooding levels on floodplain soils. Currently fewer soil conservation structures and retention ponds are being built and maintained than in the past. Many levee breaks occurred despite efforts to rebuild, raise and strengthen the Mississippi and Missouri levees following the 1993 flooding.

2.2 Case Study 2: Impacts of 2011 Len Small Levee Breach on Private and Public Illinois Lands

Agriculture, the most extensive land use of the Mississippi River Basin over the past 200 years, has altered the hydrologic cycle and changed the regional energy budget [13]. Extensive systems of public and private levees along the Mississippi River near Cape Girardeau, Missouri and southward channel the river and protect low-lying agricultural lands, rural towns, and public conservation areas from flooding [7, 13]. The flood of 2011 severely tested these levee systems. One of these critical levees, the Len Small (Fig. 7), a private levee, was topped and failed creating a 1,500 m breach as the Mississippi River poured through the gap souring farmland, depositing sediment, and creating gullies and a crater lake [7]. The Len Small levee and another connecting private levee, the Fayville located in Alexander County on the southwestern Illinois border north of Cairo, were built for 20-year floods. Together they form a 34 km long barrier between the Mississippi River and 24,000 ha of farmland and public land including the Horseshoe Lake Conservation area (Fig. 8) on the western edge of the Cache River Valley.

The agricultural lands which surround Horseshoe Lake, an oxbow lake, are mostly Weinbachsilt loam, Karnaksilty clay, Sciotoville silt loam and Alvin fine sandy loam and are highly productive bottomland soils [14]. By early May of 2011, the floodwaters at the Ohio River flood gage in Cairo, Illinois had reached 18.7 m

Fig. 7 Len Small farmer district levee near Miller City, Illinois.

Fig. 8 Bald cypress in Horseshoe lake conservation area (Illinois).

[15] reflecting an Ohio River 6.7 m above flood stage. The flooded Ohio River caused the back-up of Mississippi River floodwater north of the Cairo Confluence placing significant pressure on the Len Small and Fayville levees. The May 2 topping and breach of the Len Small levee occurred just a few hours before the pressure of record flood levels was relieved with the USACE induced breach of the levee at Birds Point, at the top of the New Madrid Floodway just below the confluence of the Ohio and Mississippi rivers. At the same time, the eastern portion of the Cache River Valley was flooded through the Karnak levee breach from the Ohio River. As a result about 4,000 ha of farmlands lost the winter wheat crop or were not planted in 2011 and about half of that land had significant soil damages including land scouring and sediment deposition or was slow to drain. Crater lakes, gullies and sand deltas were created near the Len Small breach thereby removing agricultural land from production. The 2011 Illinois agricultural statistics for Alexander County recorded 1,800 fewer harvested hectares of corn and 2,600 less hectares of soybeans compared to 2010. Approximately, one third of the area (16,000 ha) is in public lands including Shawnee National Forest, Santa Fe Hills, Burnham Island Conservation, Horseshoe State Conservation area (Fig. 8), Goose Islands, Big Cypress and the land adjacent to the Len Small and Fayville levees. These areas also sustained flood damage but were more resilient than the private agricultural and urban lands. These Mississippi River bottomlands are riparian forests-transition ecosystems with fertile, fine-textured soils that are enriched by nutrients and sediments deposited during flooding. Bottomland soils that flood

periodically have hydrophytic plants and hardwood forests which provide preferred habitat for both resident and migratory birds. Alluvial bottomland species are well adapted to seasonal flood cycles which can last several days to a month or more [16].

Impacts of the natural breach included the loss of the 2011 wheat crop and crop production loss from 4,047 ha to 8,094 ha of alluvial soils which were not planted in 2011. Much of Alexander County farmland dried out sufficiently by fall of 2011 to permit planting of wheat. It appears that all soils dried sufficiently to allow the planting of corn and soybeans in spring of 2012. Not all Alexander County (Illinois) farmers had crop insurance so it is not clear how much 2011 farm income replacement came from flood insurance. Many roads and state facilities were damaged by floodwaters which passed through the Len Small and Karnack breaches. During the fall of 2011, local farmers and members of the Len Small Levee District patched the Len Small levee by creating a sand berm a meter lower than the original levee. They asked the USACE to cover the levee with a clay cover or cap and restore it to at least the original height. The USACE agreed to do this in August of 2012 after receiving additional federal funds. Some individual farmers created berms around their farmsteads to protect their homes (Fig. 9), barns, out-buildings and equipment from any future flooding that might occur. The repair of the breached levee, crater lake, gullies, and sand deltas began in October of 2011 and continued until November of 2012.

2.3 Case Study 3: The Impacts of 2011 Induced Levee Breaches on Agricultural Lands of Mississippi River Valley

A natural breach in a levee can occur for a variety of reasons including construction techniques, burrowing animals, friable soil, fast-moving current scouring out

Fig. 9 Berm around home near Miller City, Illinois.

the levee base, wave action from wind or passing barges, with the biggest danger of all the constant unrelenting pressure from the river above flood stage [17]. The longer the river presses against the levee, the more saturated and weaker it becomes with part of it sloughing off or the river weight pushes water underneath the levee creating sand boils behind the levee and eroding the core of the levee. Natural breaches happen unexpectedly, requiring emergency measures and have high potential for great harm to lives and properties. However, the deliberate breaching of the levees (Fig. 10) in the New Madrid Floodway below Cairo in May 2011 was a planned strategy by the USACE to reduce water pressure and prevent levee failures where harm to human life might occur. The induced breach resulted in the flooding of 53,824 ha of Missouri farmland, the loss of the 2011 wheat crop (Fig. 11), delayed planting of soybeans and damage to soil productivity upon which future crops depend. Although some soil damages were expected under flooding conditions, the strong current and sweep of water through the Birds Point breach created deep gullies in several places, displaced tons of soil, damaged irrigation equipment (Fig. 12), farm and home buildings. Extensive excavation of sediment-filled ditches, filling of craters and gullies, incorporation of thin sand deposits into the plow layer of fields and the re-distribution of soil as well as the rebuilding of the levee system were all tasks necessary for Missouri farmers to plant and grow crops in 2012.

The starting point of the lower Mississippi River is the confluence of the upper Mississippi River and the Ohio River at Cairo, Illinois, 84.8 m above sea level. After the deadly 1927 flood, the USACE designed the

Fig. 10 Birds Point (Missouri) man-induced levee breach.

Fig. 11 Drowned wheat crop on May 20, 2011 in Birds Point-New Madrid (Missouri) floodway.

Fig. 12 Toppled irrigation equipment in Birds Point-New Madrid (Missouri) floodway.

Birds Point-New Madrid Floodway as part of a larger Mississippi River Basin plan to manage the river and control flooding when the Ohio and Mississippi rivers threaten to overflow the frontline levees (Fig. 13) and floodwalls (Fig. 14). The floodway is approximately 53.1 km long and is between 6.4 km and 16.1 km wide and enclosed by frontline and setback levees except for a 457 m gap at the lower end which serves as a drainage outlet (Fig. 15) and allows flood backwaters to enter the Mississippi River. The frontline levee includes an upper fuse plug section 17.7 km long, a lower fuse plug section 8 km long and the section of 24 km long frontline levee connecting the two plugs. The frontline levee was constructed to protect the floodway until the Mississippi River reached the 16.8 m stage at Cairo gage at which time the floodwater would naturally overtop it.

The hundreds of kilometers of levees on the west side of the Mississippi River, including the 57.9 km and 20 m high setback levee of the New Madrid Floodway and the Commerce to Birds Point levee protect 1.0 million ha of agricultural bottomlands adjacent to and south and west of the floodway setback levee (mostly in Missouri and Arkansas) [18]. These levees held before, during or after the opening of the floodway and the 2011 agricultural production from this 1.0 million ha region was protected. The amount of temporary water storage (at initial depths from 1.8 m to 3.7 m and pass through water in the New Madrid Floodway and on basin Caruthersville, Commerce, Dundee and Forestdale soils) was 25 times to 28 times greater than what could have been stored (as a result of levee failures) in the Cairo and Future City areas and adjacent agricultural areas of Illinois if the Cairo and Future City floodwalls or levee system were naturally breached.

The induced breach and flooding of the New

Fig. 13 Cairo (Illinois) levee on Mississippi River.

Fig. 14 Cairo (Illinois) floodwall on top of the Ohio River bank.

Fig. 15 Sediment removal from main drainage ditch which drains southern 40,000 ha of Birds Point-New Madrid (Missouri) floodway.

Madrid Floodway and basin (470 km^2) resulted in significant crater lakes at two locations where the TNT (trinitrotoluene) explosives were used (Birds Point fuse plug and frontline levee near Big Oak Tree State Park, MO). The extra force of the rushing water widened the holes in the levees (2 km) at Birds Point fuse plug and created six crater lakes in the levee fuse plug and adjacent to it. Each Birds Point crater lake was approximately 0.5 ha in size next to the degraded levee area. There were gullies extending into the agricultural fields from the crater lakes. Sand deltaic deposit 0.3 m to 1.5 m thick and approximately 3 ha to 20 ha in size were created in fields adjacent to the crater lands. The crater lakes, gullies and the thick sand deposits will result in a permanent loss of agricultural land unless the sand is removed, used to fill the crater lakes and gullies or used in patching the levees (Figs. 16 and 17). The frontline levee near Big Oak Tree State Park had only one 6.4 ha crater lake extending through the levee and a thick 1 m to 2 m deltaic sand deposit approximately 30 ha in size with additional sand deposits between 0.3 m and 2 m and more than 70 ha in size. This thick deltaic sand deposit required removal before the land could be planted to crops. The drainage (Fig. 18) and road (Fig. 19) ditches were filled 0.9 m to 1.8 m of fine sediment and sand.

There were several hundred hectares of cropland land with huge gullies created on ridges that were scoured (eroded) as the rapidly moving initial water flowed over the higher flatland surface (Dundee silt loam soils [19]) and then dropped back to lower bottomland soils to the west and south.

Fig. 16 Ongoing repair of Big Oak Tree (Missouri) frontline levee breach.

Fig. 17 Completed repair of Big Oak Tree (Missouri) frontline levee with tarp to protect levee during the winter.

Fig. 18 Cleaning out drainage ditch in Birds Point-New Madrid (Missouri) floodway with drag line.

Fig. 19 Cleaning out highway ditch in Birds Point-New Madrid (Missouri) floodway with excavator.

This rapid cutting of floodwater created turbulence and eroded the higher Dubbs and Dundee soils. Once an erosional channel was created, the channel concentrated the water and in some cases up to 1 km long gullies (channels) were created during this one time use of the floodway. Most of these gully fields (Fig. 20) are located 8 km to 16.1 km to the southwest of the Birds Point levee breach. They are not connected to the crater lakes next to the levee breaches. Some of the gullies are 3.7 m deep, 45.8 km wide and 1 km long; and a number of fields had less than 1/2 of each field planted to soybeans in late June and early July of 2011. The force of floodwater which created these large gullies also washed out road beds and road bridges. Further degradation of county roads occurred from trucks hauling soil materials for reconstruction of the area.

3. Conclusions

Climate change will amplify the risks associated with snow melt, rainfall, runoff patterns and flooding [20]. Shifts in global temperatures are likely to have substantive effects on the water cycle as the amount of water vapor that the atmosphere can hold increases rapidly at increasing temperatures, leading to more extreme and less predictable rainfall events and 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 future events. Levees are complex engineered systems coupled with natural and social

Fig. 20 O'Brien Ridge gully field with canyon sized gullies in Birds Point-New Madrid (Missouri) floodway.

systems. Due to incomplete knowledge of these dynamic systems and how they interact, future levee re-designs must not only account for risks to the engineered system but how to build in social, economic and environmental resilience.

4. Recommendations

Three recommendations emerge from our documentation and analyses of the three 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 of 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. Further, 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 a 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 as a result 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. [21] 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 can not 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 contamination and improving the overall resilience of agricultural productivity in deltaic environments.

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