CLAY CONTENT OF LEVEE EMBANKMENTS AND ITS ROLE IN SURVIVABILTY OF LEVEES DURING OVERTOPPING EVENTS

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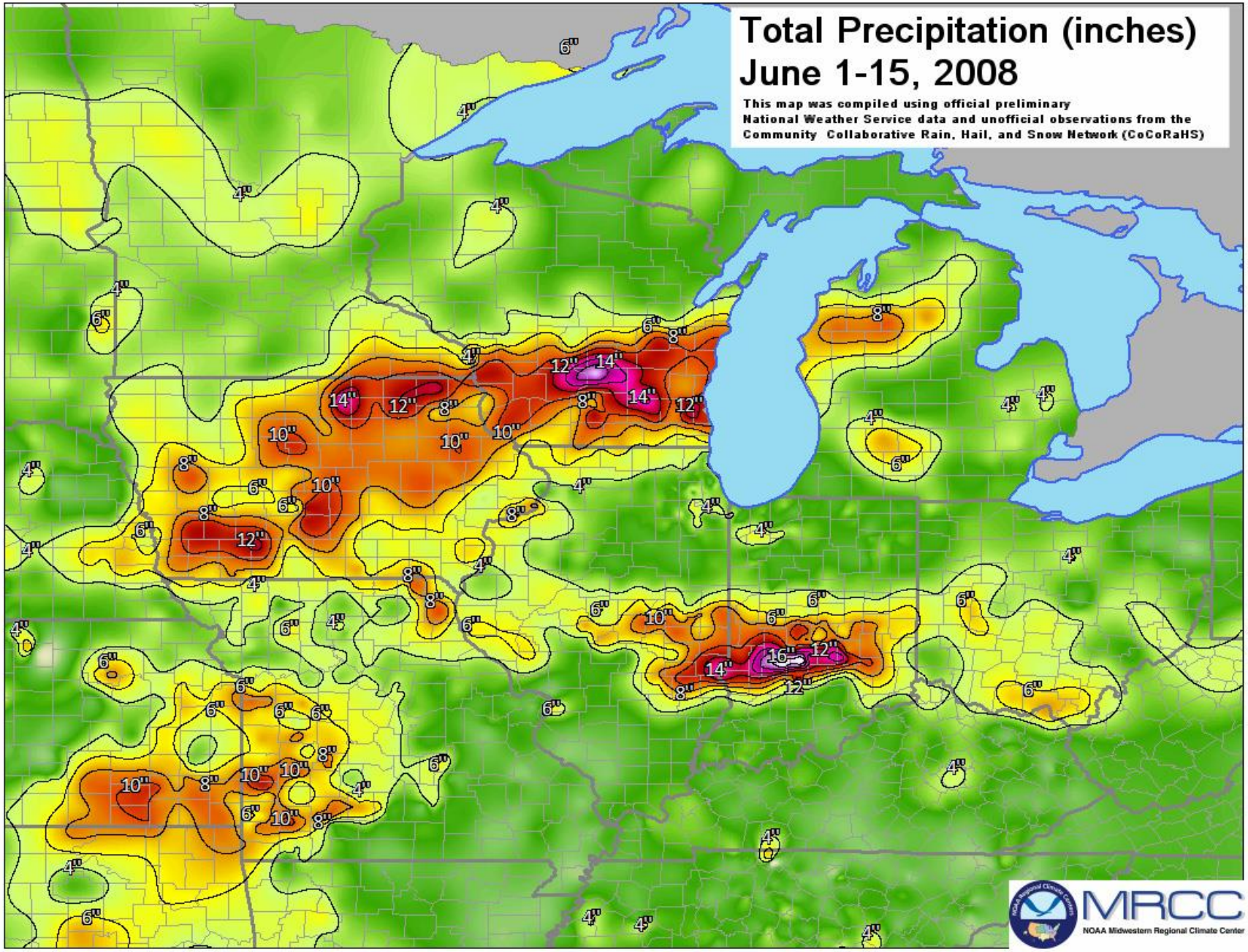
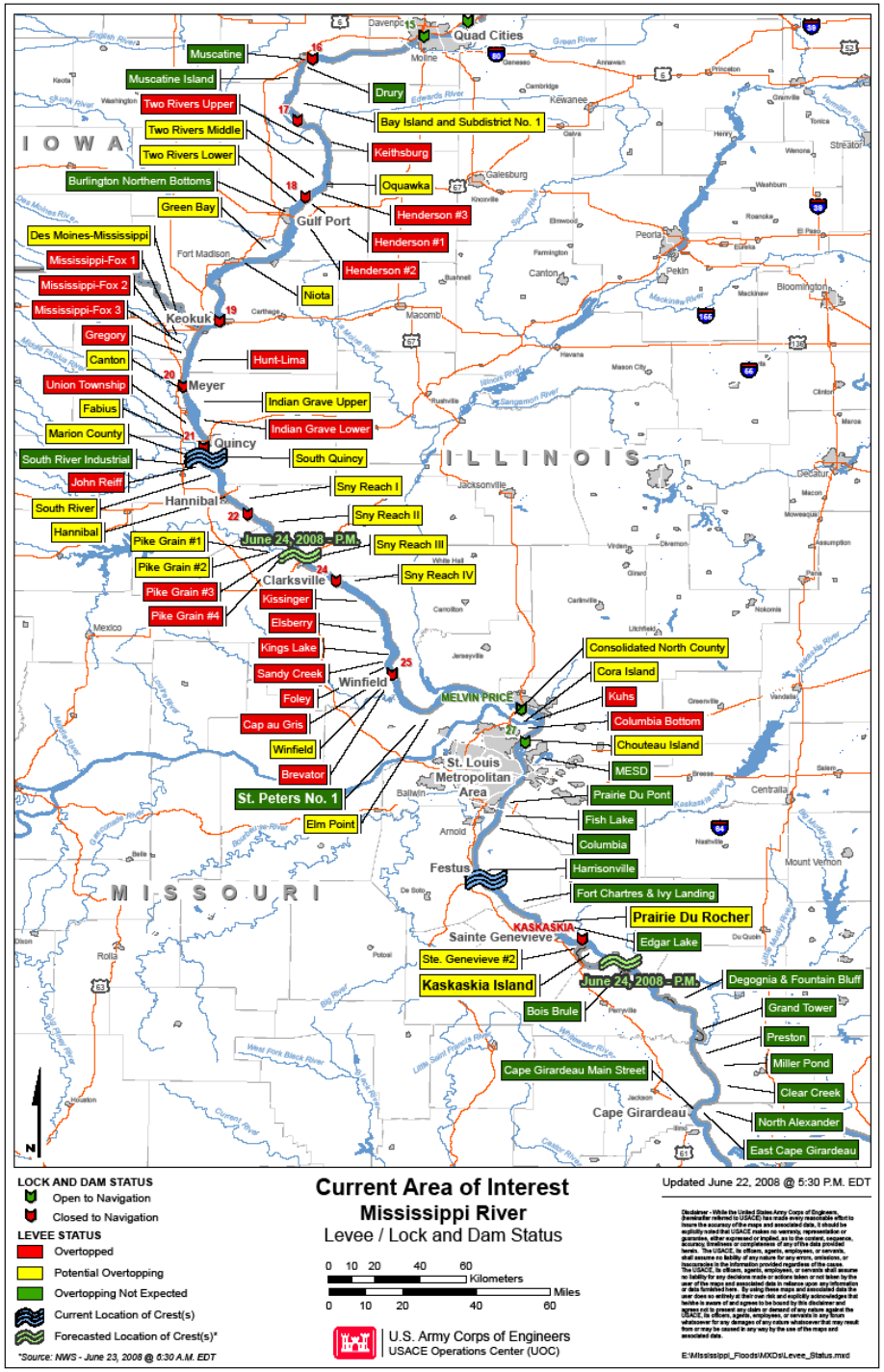
for the symposium on

Geologic Studies for Dams and Levees
Association of Environmental & Engineering Geologists
Lake Tahoe, California
September 25, 2009


Total Precipitation (inches)
June 1-15, 2008
This map was compiled using official preliminary
National Weather Service data and unofficial observations from the
Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS)
MRCC
NOAA Midwestern Regional Climate Center



Summer 2008 Midwest Floods

- Largest runoff event since 1993
- Record flows on lower Iowa River in Iowa and Salt Creek near Hannibal, MO
- No significant impacts on flood infrastructure downstream of St Louis
- Corps of Engineers dams probably shaved 1.5 to 3.5 feet off the peak flows

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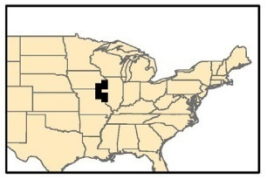
Lock and Dam No. 22 at Saverton closed on June 14th



2008 Midwest Levee Investigation
Study Sites

30 15 0 30 Kilometers

N
W E
S

Sites selected for further study

- Kehs
- Brevator
- Winfield
- Cap au Gris
- Kings Lake
- Elsberry
- Kickapoo
- Bryants Creek
- Indian Graves
- Two Rivers

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Winfield-Pillsbury breach on June 18th. Note overtopping.

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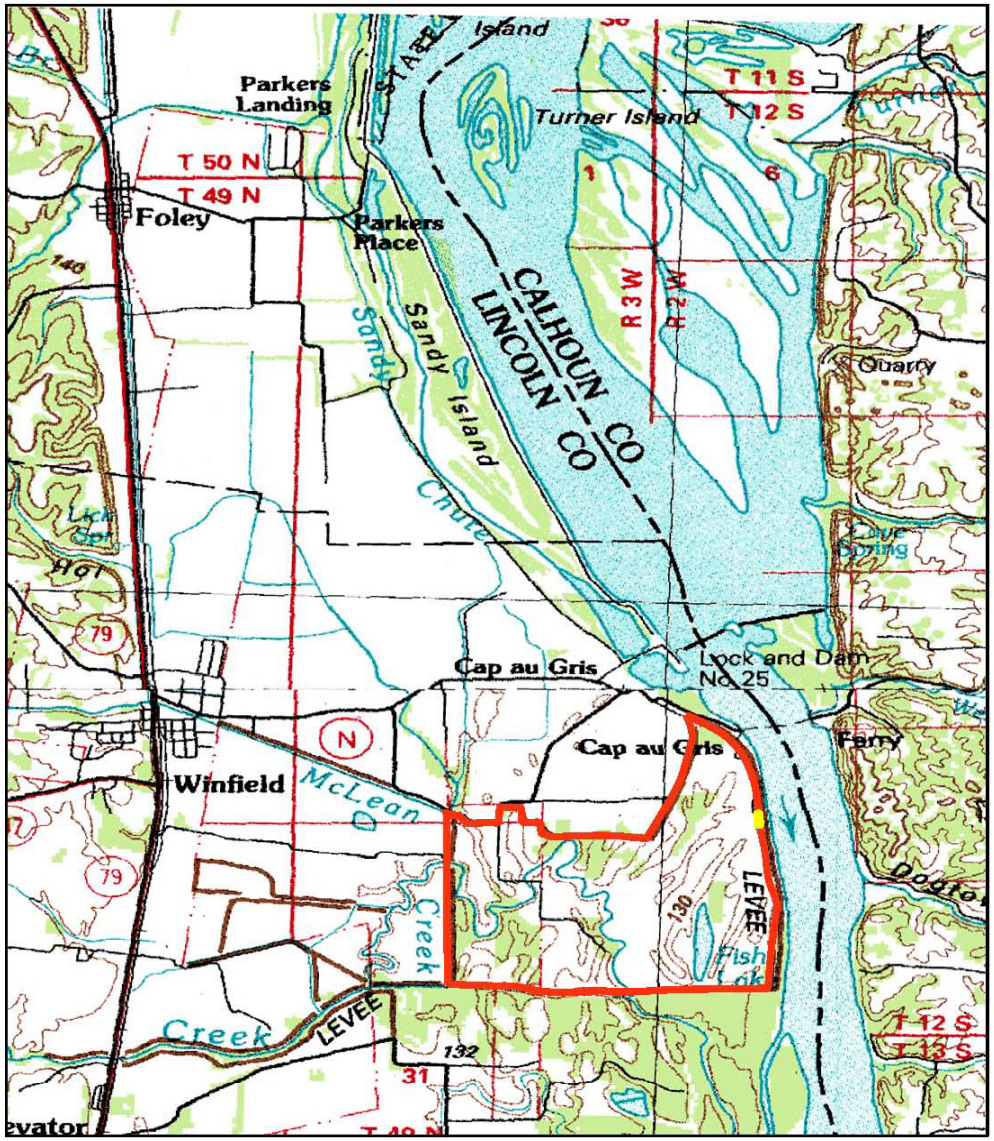
Second story of house being rafted from Winfield-Pillsbury

Cap au Gris Levee District

- Three breaks, all along the right bank of the Mississippi River



2008 Midwest Levee Investigation - Winfield Pin Oaks Breach

Legend

Winfield_Breach

Winfield_Levees

1,500 750 0 1,500 Meters

N W E S

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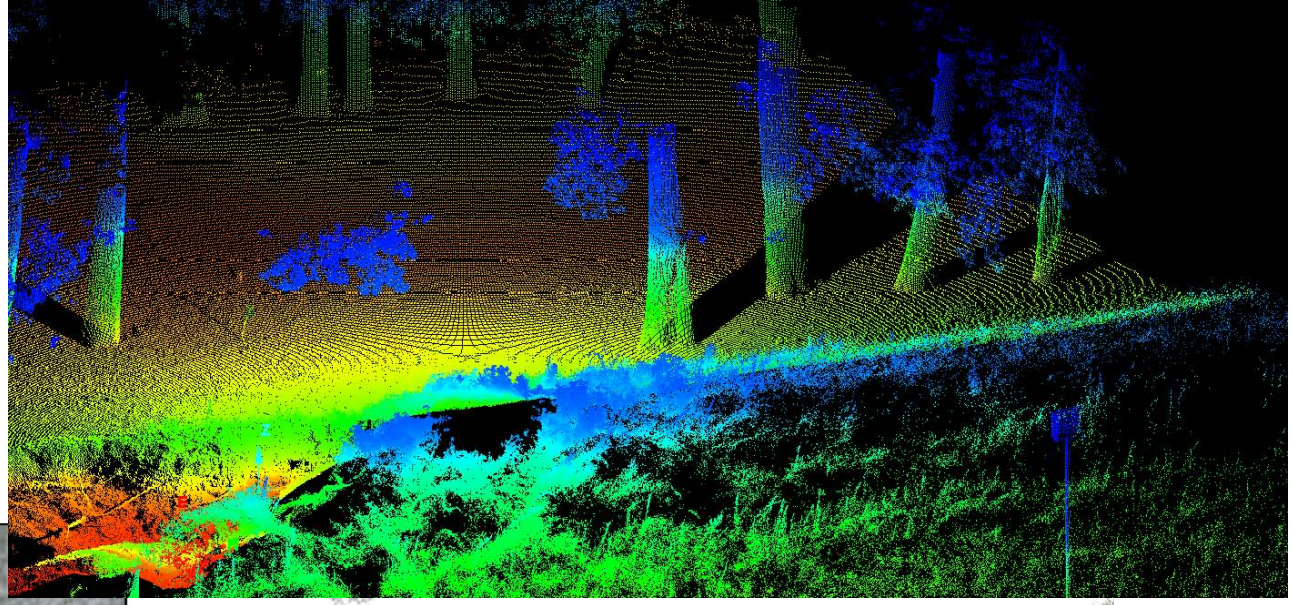
- **Cap au Gris breach which we surveyed and sampled. Very sandy silt.**

Off-the-shelf technology

- Rod ‘n reel
- Sonar fish finder; allowed us to see downed trees
- GPS receiver
- Rubber raft

- **Seepage paths** often influenced by features such as tree root tracks, crayfish and/or ground squirrel burrows
- **Permeability** of silty earthen dikes close to the modern channel is about 1×10^{-3} cm/sec, or about 3 ft/day

Ground based LiDAR



Comparing silt lines on trees with levee crests

- **In the old days we were obliged to survey mud lines on structures to get maximum flood heights**

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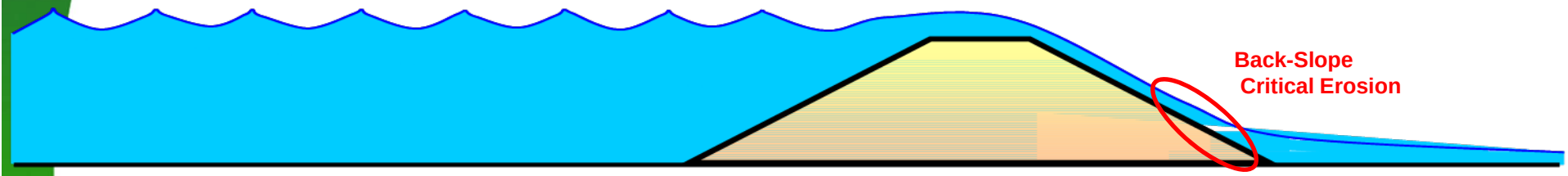
Lock and Dam No 25 near Winfield closed down June 15th

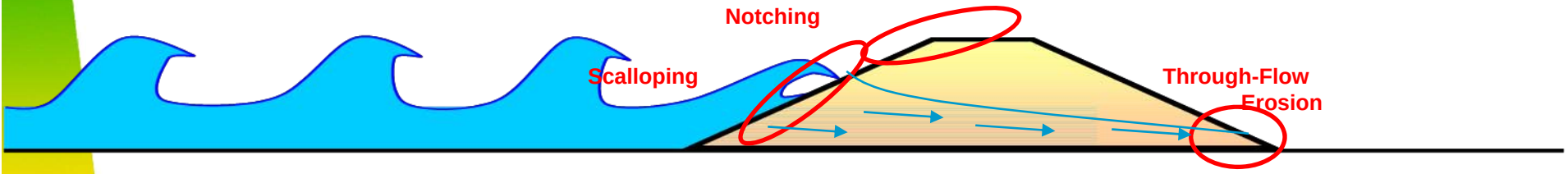
- **The Brevator District levees near Winfield survived 14 days of near-continuous overtopping, without failing**

- **Erosion tests of samples recovered from the Brevator Levees revealed they have a much higher clay content than levees closer to the Mississippi River which did not survive overtopping.**

Two kinds of overtopping-induced damage

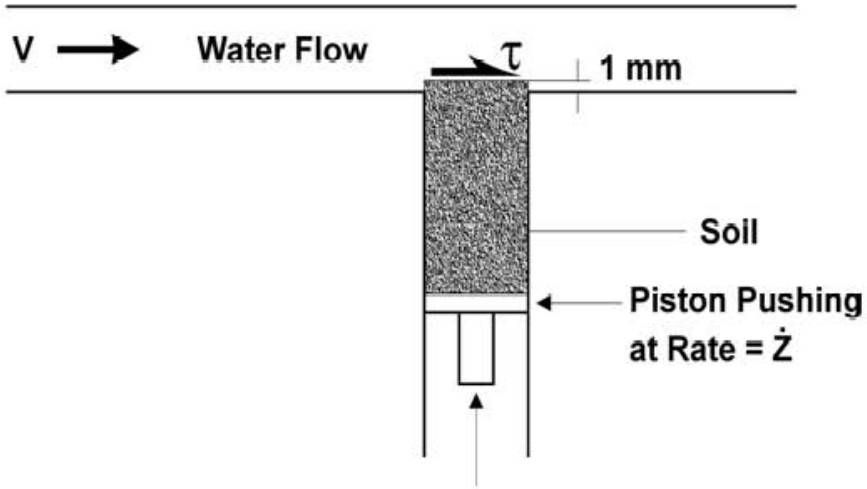


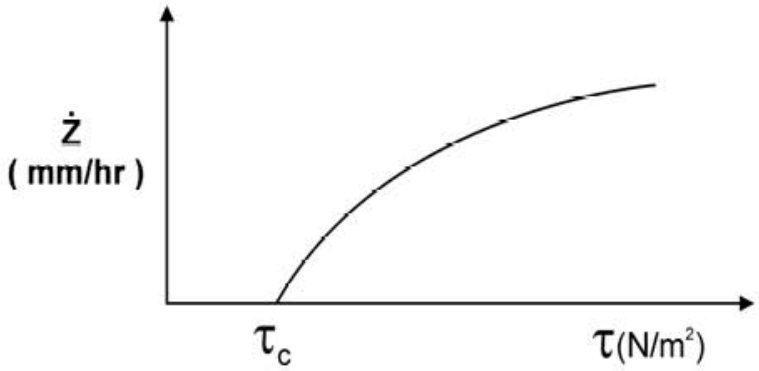
Velocity-induced scour at toe of back slope, at flow transition.
Accelerates when vegetation stripped off, depending on cohesion of embankment materials



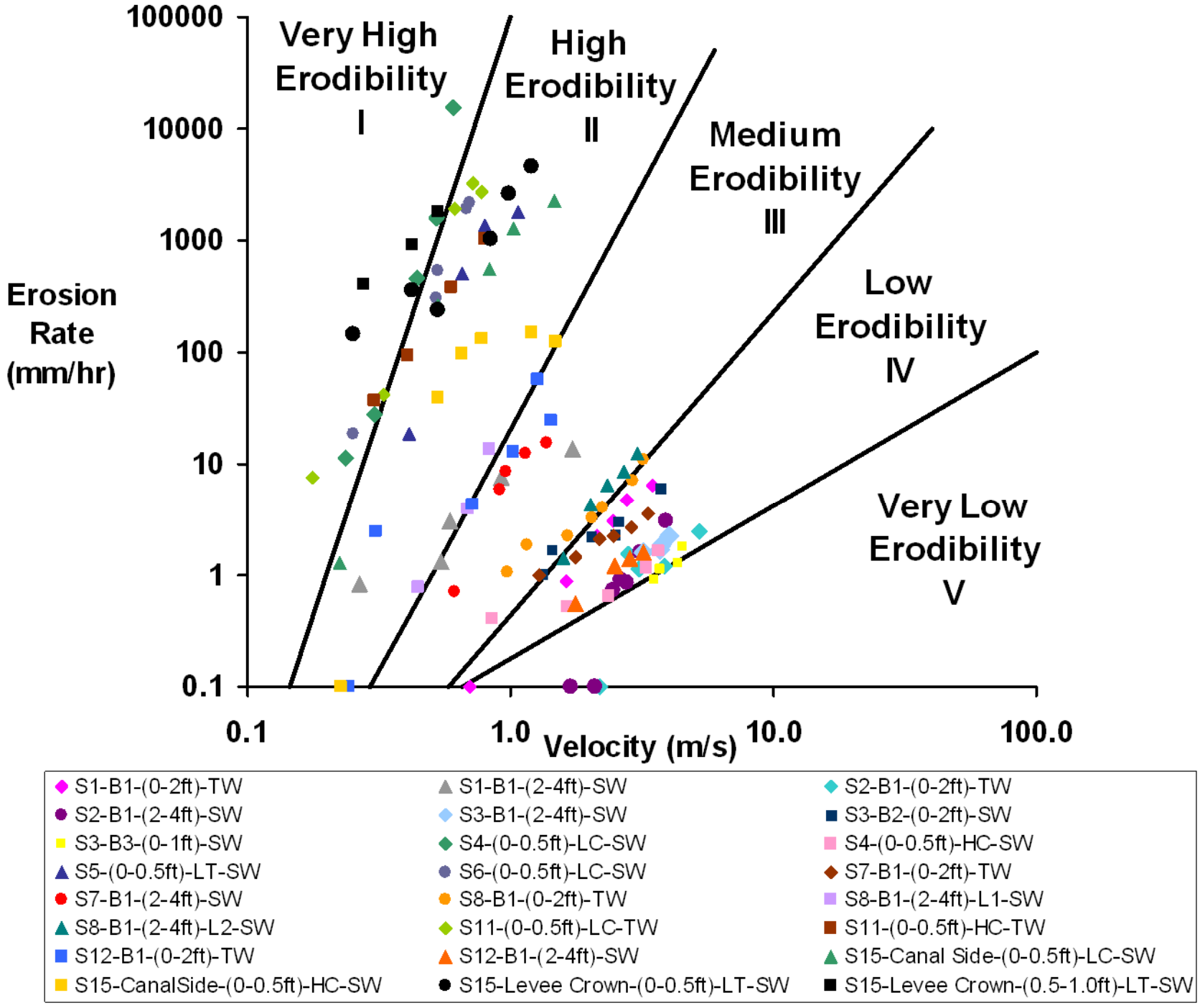
Scalloping and notching on the fetch side of the levee, due to wave pounding; and piping fomented by emergent seepage at the toe of the back slope

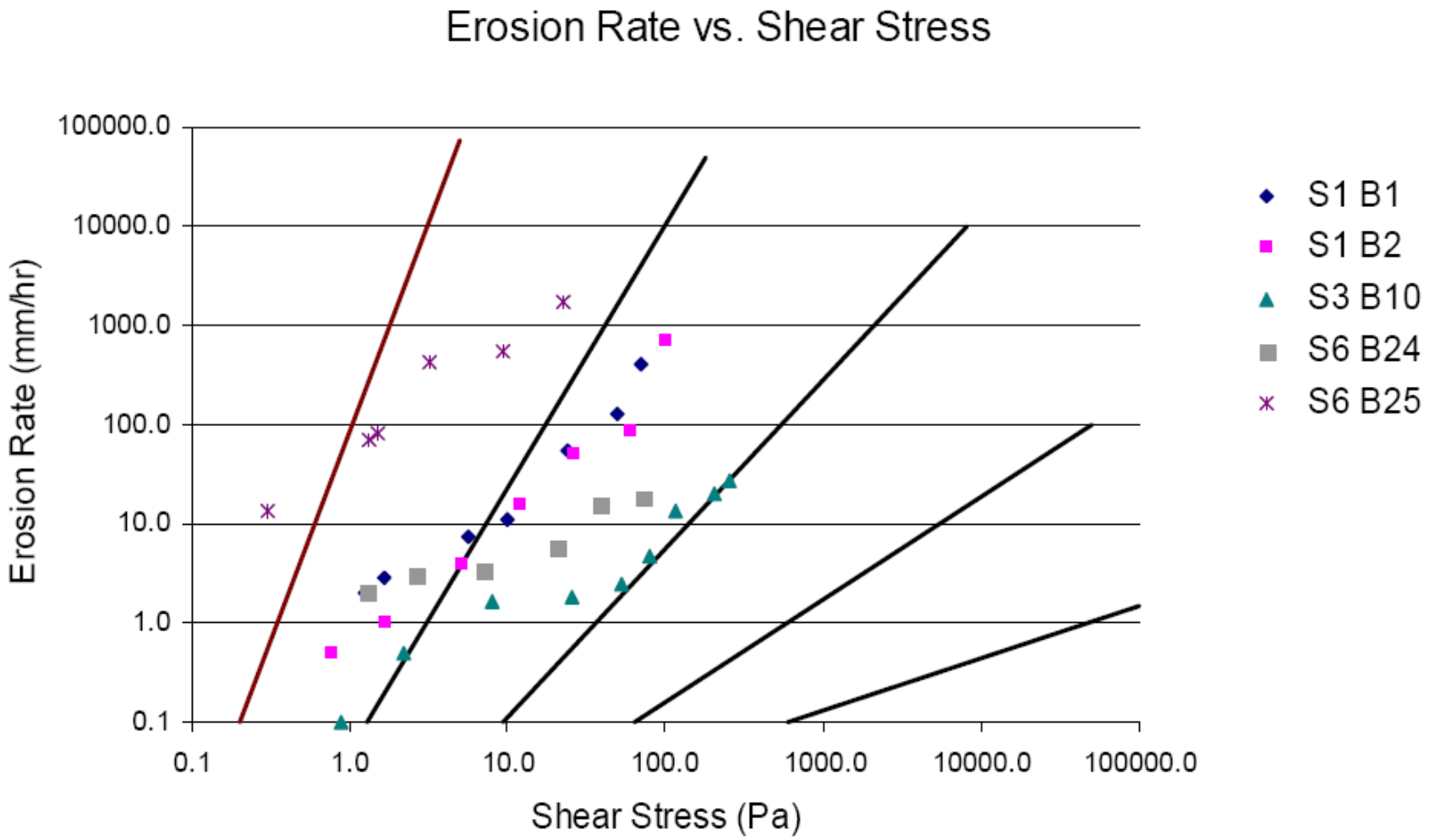
Note: damage at back slope toe looks similar for both modes



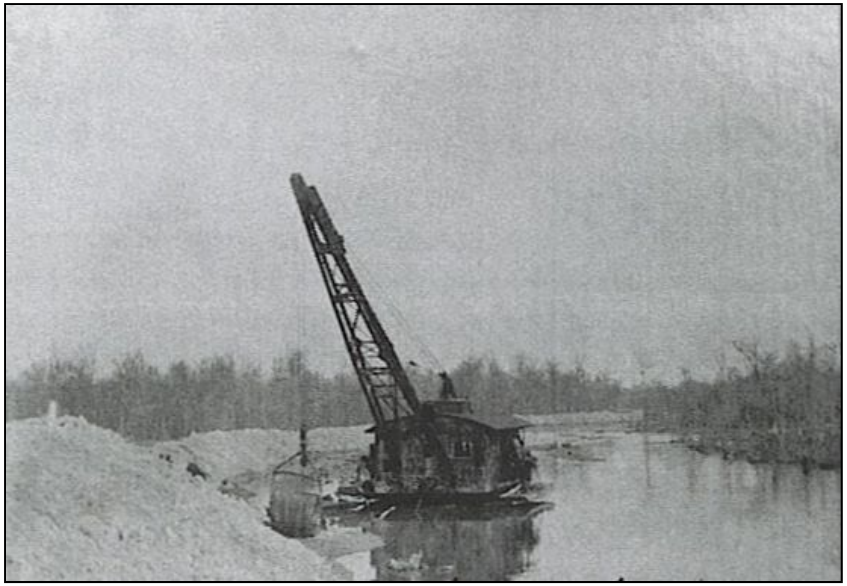


- **Soil erodability test apparatus developed by Prof. Jean-Louis Briaud at Texas A&M University**

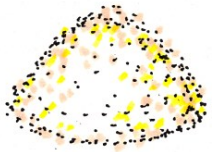

Very High Erodibility I
High Erodibility II
Medium Erodibility III
Low Erodibility IV
Very Low Erodibility V
Erosion Rate (mm/hr)
100000
10000
1000
100
10
1
0.1
0.1
1.0
10.0
100.0
Velocity (m/s)
S1-B1-(0-2ft)-TW
S1-B1-(2-4ft)-SW
S2-B1-(0-2ft)-TW
S2-B1-(2-4ft)-SW
S3-B1-(2-4ft)-SW
S3-B2-(0-2ft)-SW
S3-B3-(0-1ft)-SW
S4-(0-0.5ft)-LC-SW
S4-(0-0.5ft)-HC-SW
S5-(0-0.5ft)-LT-SW
S6-(0-0.5ft)-LC-SW
S7-B1-(0-2ft)-TW
S7-B1-(2-4ft)-SW
S8-B1-(0-2ft)-TW
S8-B1-(2-4ft)-L1-SW
S8-B1-(2-4ft)-L2-SW
S11-(0-0.5ft)-LC-TW
S11-(0-0.5ft)-HC-TW
S12-B1-(0-2ft)-TW
S12-B1-(2-4ft)-SW
S15-Canal Side-(0-0.5ft)-LC-SW
S15-CanalSide-(0-0.5ft)-HC-SW
S15-Levee Crown-(0-0.5ft)-LT-SW
S15-Levee Crown-(0.5-1.0ft)-LT-SW

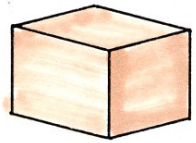


- **Erodability data for Midwestern Levees sampled after the 2008 floods**



COHESIONLESS **vs** **COHESIVE**



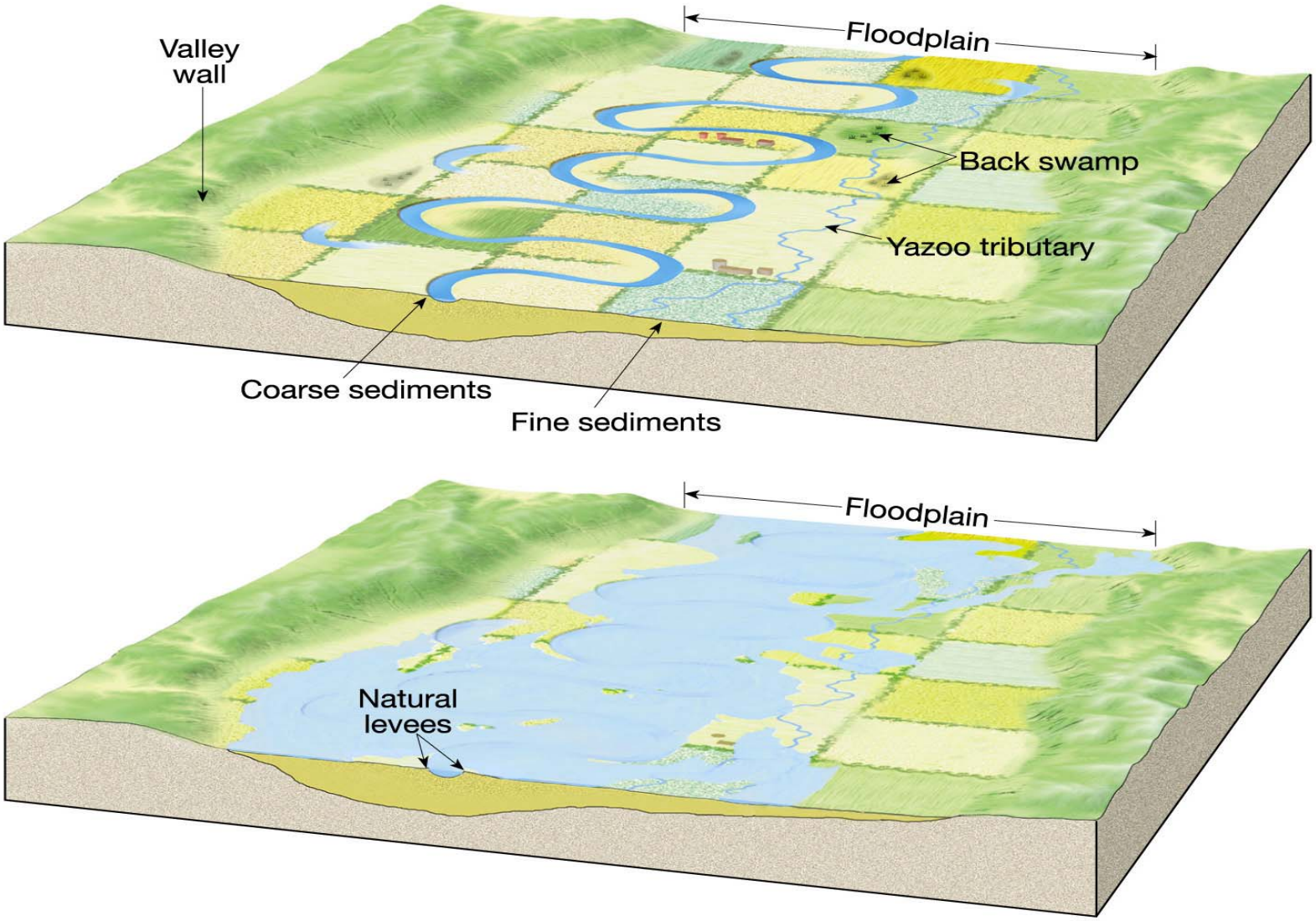


sand –
no glue
lots of friction

clay –
lots of glue
little friction

The key to levees surviving overtopping is the clay content. Much of the dredged material consisted of organic silt, which does not have substantive cohesion

Natural levees and floodplains



LiDAR derived relief map of the lower Cuivre River, employing 1 m posting. Note cut-offs employed between meander bows on the Mississippi flood plain

DOQQ imagery wrapped on the LiDAR and DEM surface, showing development of the Mississippi River flood plain at mouth of the Cuivre River.

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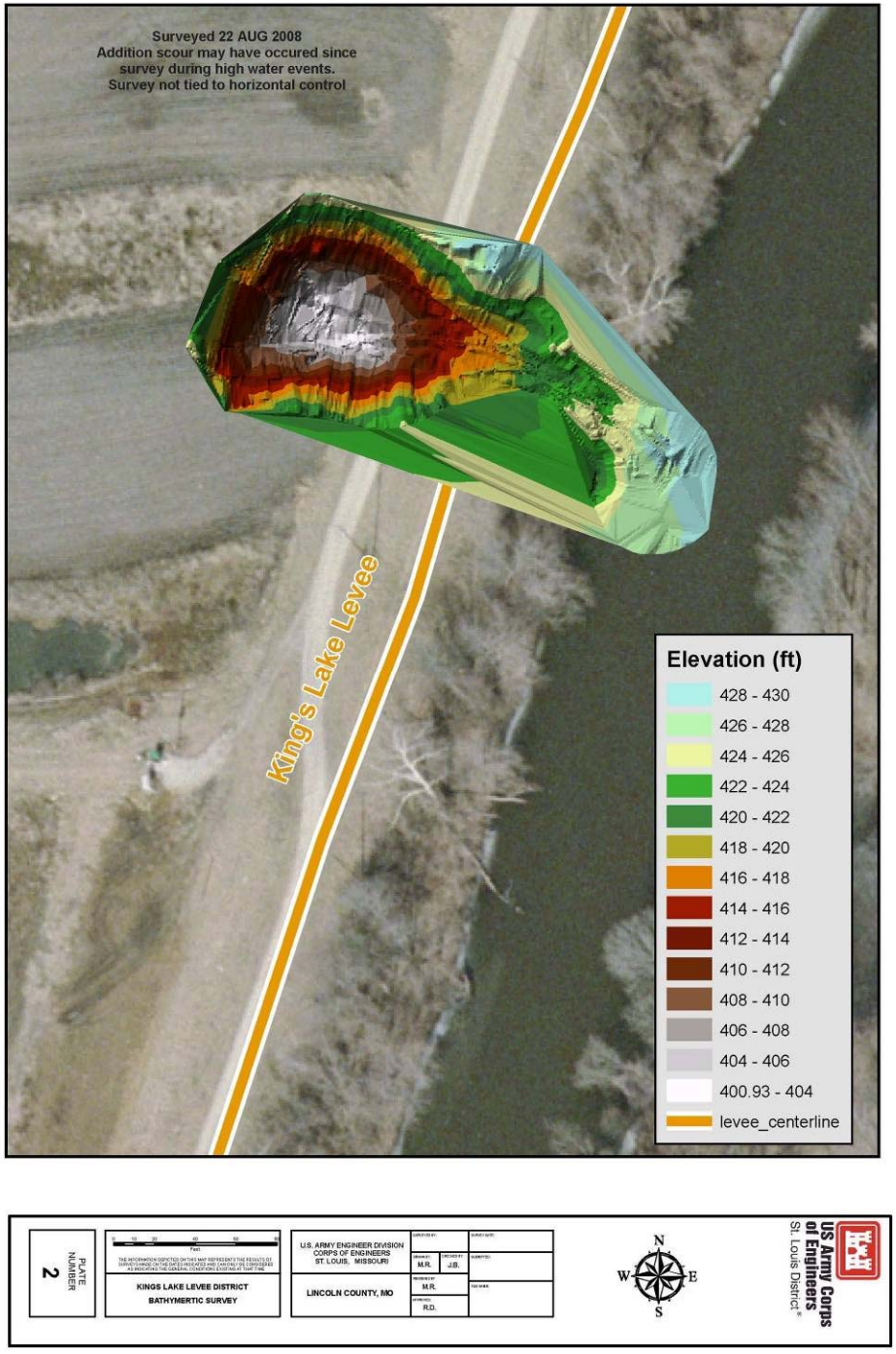
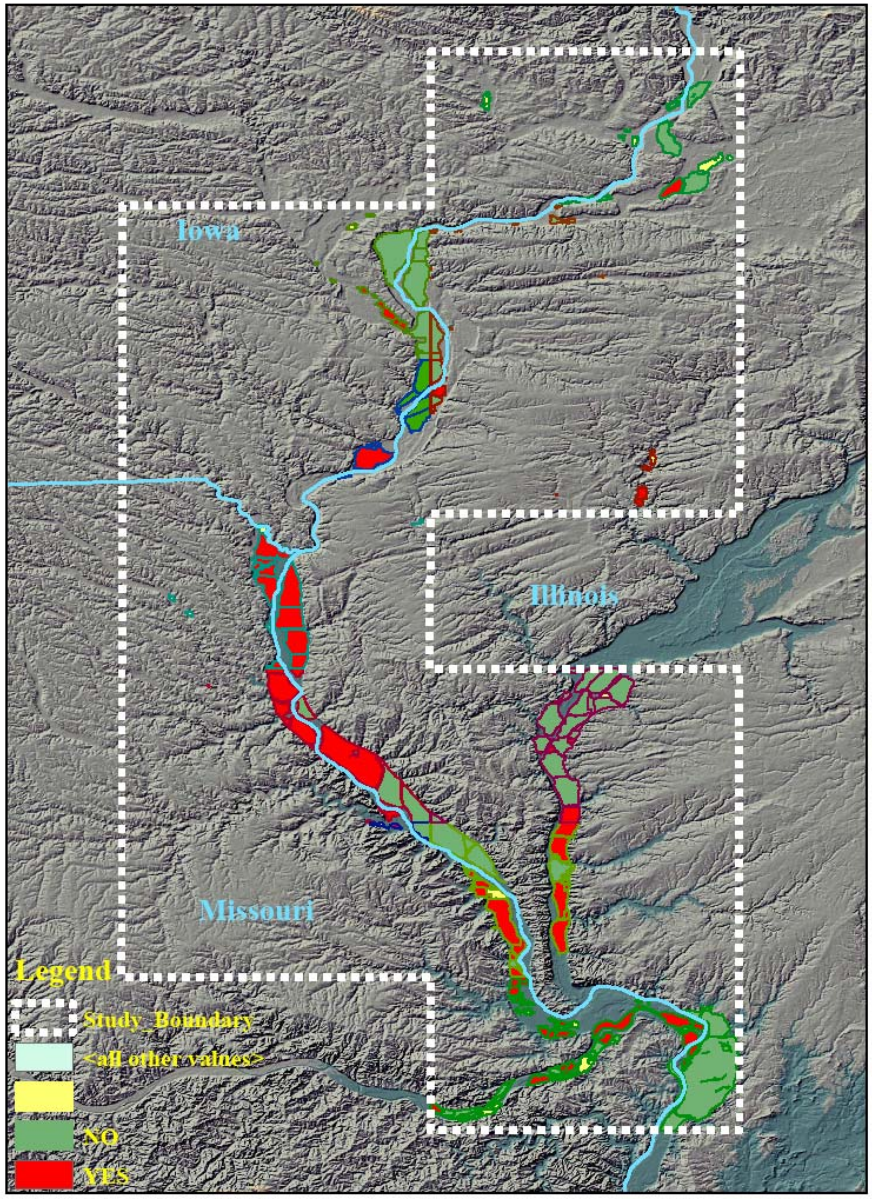


Biggest Repair Problem

- Deep scour holes are perhaps the biggest engineering challenge in repairing dikes.
- These hole can be up to 40 ft deep and are backfilled with dredged sand
- A 5 ft thick clay cap is compacted over the sand fill to provide a semi-impervious seepage ‘blanket’

The existing levee system is antiquated

- **Levees were originally placed to reclaim floodplains for agricultural development and to protect urban commercial centers.**
- **Levees and floodwalls have allowed continuing development of urban commercial centers**
- **The risk-consequence of a levee failure in densely populated areas can be several orders of magnitude greater than within most agricultural tracts**
- **Since 1990 our national policy has shifted to promoting the removal of urban developments off the flood plains, whenever possible.**



2008 Midwest Levee Investigation
1993 Levee Breach Locations

50 25 0 50 Kilometers

N
W E
S

Making levees more resilient – and survivable

- The NSF-funded team is focusing on areas where levees have repeatedly failed
- And, places where levees survived sustained overtopping, sometimes for several weeks

In the 21st Century we will face economic pressures to make levees more resilient

- Levees need to be made more survivable.
- Some of the greatest damage occurs at forced breaches, to drain inundated tracts
- Levees could be retrofitted with engineered overflow weirs
- Rudimentary outlet works should be installed at the down-gradient ends of agricultural tracts, to obviate need for forced breaches
- Some environmentalists and civil engineers have advocated returning 25% of reclaimed floodplain, and promoting aquaculture crops in the lowest areas ("nutrient farms")

Aging Factors

that plague geotechnical engineers designing levees:

1) Erosion/aggradation impacts
2) Differential settlement
3) Changes in channel geometry, roughness, flow quantities, flood storage, recurrence frequencies, risk-consequence models, etc.

With Much Appreciation

- National Science Foundation Engineering Directorate-CMMI Division
- U.S. Army Corps of Engineers, St Louis and Rock Island Districts, who provided images, maps, and historical background
- USGS-WRD and NWS for flow data
- Local levee and drainage districts
- University of California, Berkeley geotechnical disaster reconnaissance team
- Texas A&M University Geotechnical Engineering Program
- Prof Robert Criss at Washington University
- Dr. Greg Hempen PE, RG of URS Consultants

This lecture will be posted at

www.mst.edu/~rogersda/levees

in .pdf format for easy downloading and use by others.

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