Learning from the ‘Great Floods’ of the Missouri River: what they tell us about resilient river management

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Flood Recovery Advisory Working Group
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CERC River Studies Branch: Interdisciplinary science to inform river management and restoration

Focal topics:

- Endangered species – Pallid sturgeon, Least tern, Piping plover, Whooping cranes...
- Invasive species – Asian carps
- Benthic macroinvertebrates, biocriteria, water quality
- Riverine habitat dynamics
- Data management strategies for riverine conservation biology
- Adaptive management, collaborative decision making
Objective: explore what can be learned from floods on the Missouri River and how can that understanding be applied to increasing resilient management.

Three take-home points:

- **Flood hazard has been altered by the history of river management.**
- **Flood hazard varies geographically due to flood origins and channel adjustments to management.**
- **Effects of long-term climate change have become discernible and indicate that flood hazard will likely increase.**
Flood Risk

- Flood risk is the product of hazard and consequence:
  
  \[ \text{Risk} = \text{Hazard} \times \text{Consequence} \]

- **Hazard**: Probability of inundation, depth, velocity; drivers.
- **Consequence**: infrastructure, crops, buildings, lives.
- **Risk**: probable loss (gain) per year.
  - Managed by combination of Hazard and Consequence

Probability: (hydrology and hydraulics drivers)

Exposure, potential loss of lives or property, increase in ecosystem services

$/year, fatalities/year, benefits/year
1.3 x 10^6 km^2 area
3,750 km long
Mainstem reservoirs: 91 km^3
10 BKWH avg. annual hydropower
1,182 km channelized for navigation
Extensive floodplains are highly valued for agriculture.
And in places, urban and suburban development – Omaha, NE & Council Bluffs, IA
Reservoirs have decreased flood peaks and sediment load.

Annual suspended sediment load at St. Louis is 17% of historical. (Jacobson and others, 2009)
Aside: River Adjustments - Lane Balance

Increasing resisting power

- Sediment size
- Hydraulic roughness

Coarse to fine transition:
- Erode
- Deposit

Stream power

- Stream slope

Bedload: Coarse to fine transition

Stream discharge: Steep to flat transition

From Lane, Chorley, 1984.
Specific gage analysis from Randall and others (2017); after USACE (2017)

A. Missouri River Stage Trends - Missouri River at Sioux City, Iowa

B. Missouri River Stage Trends - Missouri River at Omaha, Nebraska

C. Missouri River Stage Trends - Missouri River at Nebraska City, Nebraska

D. Missouri River Stage Trends - Missouri River at St. Joseph, Missouri

Incision below dam

Stage amplification, high flows including below bankfull

USGS

2011 data points represent measurements taken July–October on decreasing flows. The measurements taken in October 2011 were taken with discharges between 43,800 and 47,400 ft³/s. These measurements helped develop the lower part of the rating curve. Data on this plot for the flows at 10,000, 20,000, and 30,000 ft³/s were extrapolated. If the October–June data measurements were used, decreases from 2010 data would be in the 1 to 2 foot range. Trends over the last 30 years show some rebounding after high flows.
Geomorphic adjustments

Low-conveyance zone

Difference in CRP* compared to 1990, in meters

2002 - 1990
2005 - 1990
2017 - 1990

Kansas City

Gavins Pt. Dam

River Mile

St. Louis

*CRP = construction reference plane, water surface at 75% flow exceedance.
Data from USACE (2018)
Deposition in batture – loss of conveyance
36. The proposed levees for protecting agricultural areas would be of earth fill, with a 10-foot crown width, and side slopes of 1 on 3 on the river side and 1 on 5 on the land side, with a 2-foot freeboard above the design flood after settlement. Drainage structures would be placed through the levees as required to drain interior run-off. Where required, by foundation conditions or other special reasons, rolled fill levees would be constructed. Proposed floodway widths between levees would vary from a minimum of 3,000 feet from Sioux City, Iowa, to Kansas City, Mo., and 5,000 feet from Kansas City, Mo., to the mouth.

37. At places where there is a concentration of population and property values, such as at Sioux City, Iowa; Omaha, Nebr.; Council Bluffs, Iowa; and Gasconade Boatyard in Missouri, the levees would be rolled fill with 10-foot crown width and side slopes of 1 on 3 on the river side and 1 on 4 on the land side, with a 3-foot freeboard above the design flood. Where space is not available for levees, concrete flood walls would be constructed. Drainage structures would be provided
St. Louis, 1993 Gulf source convective storms

March 2019 “Bomb” cyclone, rain on snow

2011 Gulf source rain snow pack

1993 Gulf source convective storms

1997 Mountain snowpack

Flood geography

Sioux City

Kansas City

St. Louis,
Levee breaches

Turbidity plume

Seepage water

Normalized difference, vegetation index (NDVI) processed Sentinel 2 multispectral, 10-m data.

Contains modified Copernicus Sentinel data 2019 for Sentinel data.
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Normalized difference, vegetation index (NDVI) processed Sentinel 2 multispectral, 10-m data.
After Jacobson, Janke, and Skold (2011)

Floodplain sand deposits, 2011 flood

Flooded area, 2011 flood

Alexander, Jacobson, and Rus (2013)

USGS

After Jacobson, Janke, and Skold (2011)
Levees add local potential energy.

When focused through breaches, that energy can severely erode the floodplain.

Levee breaks can evolve through thresholds to convey sediment efficiently to the floodplain.
Levees add local potential energy.

When dissipated through breaches, that energy severely perturbs the floodplain.

Levee breaks can evolve through thresholds to convey sediment efficiently to the floodplain.

(After Bogardi and Mathes, 1969)
Berger Bottoms, Franklin County, Missouri – October 1993

Inundation crop loss $2.2 million
Geomorphic restoration $19.6 million

(Jacobson, 2003)
Data from USACE (2018); Alexander and others (2013)
Best fit statistical model (not-yet published analysis)
Odds of a levee break significantly:
- increase with decreasing channel size
- increase with decreasing constricted width
- increase with increase of change in CRP

Data from USACE (2018); Alexander and others (2013)
Annual runoff into system
Millions of acre-feet

Design year: Great flood of 1881
Future climates will produce more precipitation, higher temperatures, diminished snowpack in the Missouri River Basin. 10% increase in average annual runoff by 2050. (Bureau of Reclamation, 2012)

“It was not designed to handle this,” John Remus, USACE, quoted in NY Times (3/21/2019)
Learning from Missouri River floods:

- Flood hazard has been altered by the history of river management.
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- Effects of long-term climate change have become discernible and indicate that flood hazard will likely increase.

What does this mean for resiliency? Minimize flood risk, maximize ability to recover from floods?
Flood Risk

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  - Probability:
    (hydrology and hydraulics drivers)
  - Exposure, potential loss of lives or property, increase in ecosystem services

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<th>Consequence</th>
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<tr>
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<td>Wait for incision</td>
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Distance, meters
0 200 400 600 800 1000 1200 1400

Elevation
160 165 170 175 180 185 190 195

Old Levee  Flood Corridor  New Levee
Hydraulics
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3,000-ft floodway
5,000-ft floodway

River mile, from Mississippi River
Constricted width, meters
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Local Stage Effects, Encroachment or Room for the River

Conservation of Mass:

\[ Q_1 = A_1 \times V_1 = Q_2 = A_2 \times V_2 \]

\[ A = D \times W \]

\[ V = \frac{k}{n} D^{2/3} S^{1/2} \]

Hydraulic roughness – vegetation interaction
Boonville gage

Jefferson City gage

Hartsburg
2-dimensional modeling reach

Example cross section, below
River Widening

Levee Setback Distance

50% annual flood
25% exceedance
90% exceedance
10% annual flood


Baseline (1992)

Scenarios

Jacobson, Lindner, Bitner (2015)
Water-surface elevation differences, steady, 10-year flood

Difference in Water Surface Elevation Relative to 1992 Condition, in meters

- River widened in model

Legend:
- Black: Widen
- Blue: Setback
- Red: Widen Plus Setback
- Gray: No Levees

River Mile

USGS

Jacobson, Lindner, Bitner (2015)
Potential hydraulic attenuation on floodplains….
Unsteady 2-dimensional flow model

Used 2007 10-year flood to assess scenarios with variable levee setbacks from present day to no levees.

Jacobson, Lindner, Bitner (2015)
Little *attenuation* is apparent – not a slam dunk.
- Caveat: modeled area is relatively small, about 13 river miles, 19 square miles of floodplain.
- Deformation of rising limb suggests < 5 year flood affected
Netherlands: Room for the River.
Primary objective: flood risk reduction
- Deepen navigation channel
- Use reservoir storage where available
- Levee setbacks
- Strengthen levees if setback not possible
- Create flood corridor (high water channel)
- Lower floodplain where needed
- Lower channel training structures (dikes)
- Remove obstacles (for example, redesign bridge piers, spans)

Waal River near Druten, The Netherlands.
River is about 1,000 ft wide
Mississippi River mainline levee system
Near Memphis, TN

Designed for design flood of approximately 0.5% chance (200-year avg return interval).

Average batture width is 6.5 miles (Biedenharn and others, 2018).

River is 1 mile wide.
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**USGS**
Decision space for resilient management

- The Missouri is a complex, multi-objective system. Everything is connected.
- Multiple actions can be taken – it is a challenge to understand optimal mix, tradeoffs.
- New management design would require substantive investment in modeling alternatives for hydrology, hydraulics, socio-economic, and ecological trade-offs.
- All elements affecting flood risk reduction are expensive, some more than others.
- Changing climate -> flood hazard will increase; variability will increase.
- Changing climate -> there will be many other demands for infrastructure funds nationwide.
Thank you for your time

Spring on the Missouri – Flood of 1937
Thomas Hart Benton (1945)