Levee impacts on riverine ecosystems

Mediating effects of woody vegetation

Doug Shields, Jr.

Reasons not to allow trees on or close to levees (CIRIA 2013)

- Blowover/overturning: The overturning or blowover of a large tree may remove a large section of a levee or adjoining ground during a flood event. If on the waterside, the resulting pit may leave the levee susceptible to scour.
- Root penetration: Roots, especially when decayed, may after soil permeability or concentrate seepage along root paths.
- Woody vegetation weight and wind loading: The adverse effects of woody vegetation weight and wind loading is transferred to a levee slope.
- Scour flows: Woody vegetation may cause concentrations or eddies in the waterside or overtopping flows.
- Burrowing: Woody vegetation may attract burrowing animals into a levee.
- Discouraging adequate growth of grass and turf: Woody vegetation may prevent adequate growth of grass and turf by blocking sunlight, absorbing nutrients and moisture or releasing chemicals that act as herbicides, resulting in bare, exposed soil on levee surfaces.
- Damage to revetment: If the revetment was not designed for vegetation, the growth of roots and stems may move and loosen the stones, or rigid levee protection elements such as asphalt, grouted stone, or concrete slabs, thus affecting the revetment's interlocking characteristics.

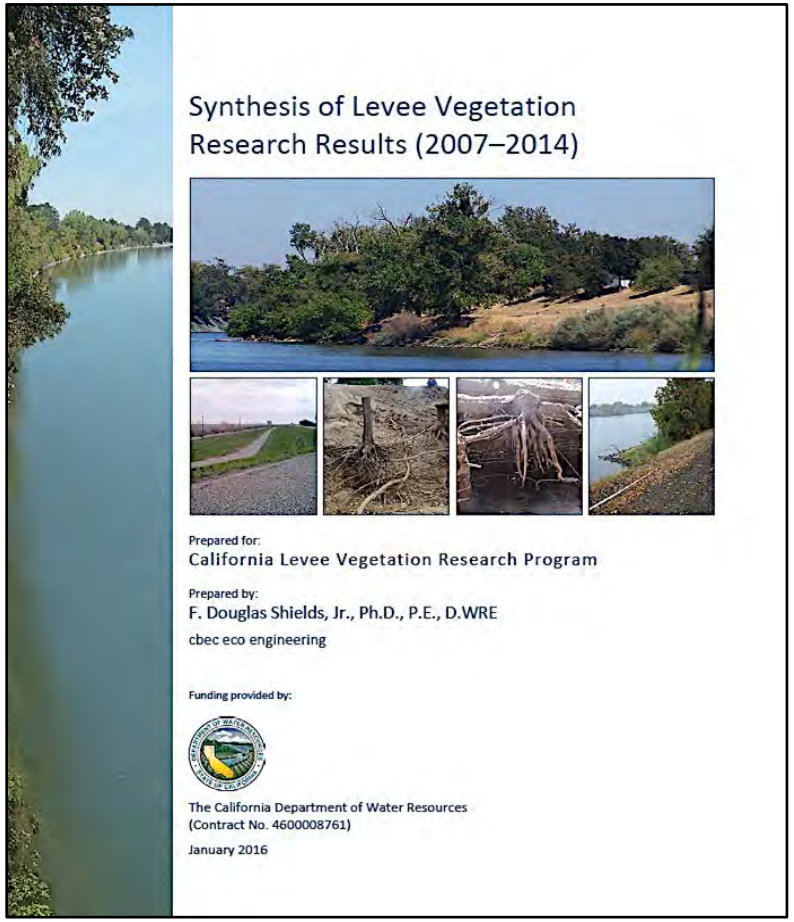
Old questions

How does woody vegetation effect risk for levees?

Is the net risk positive or negative?

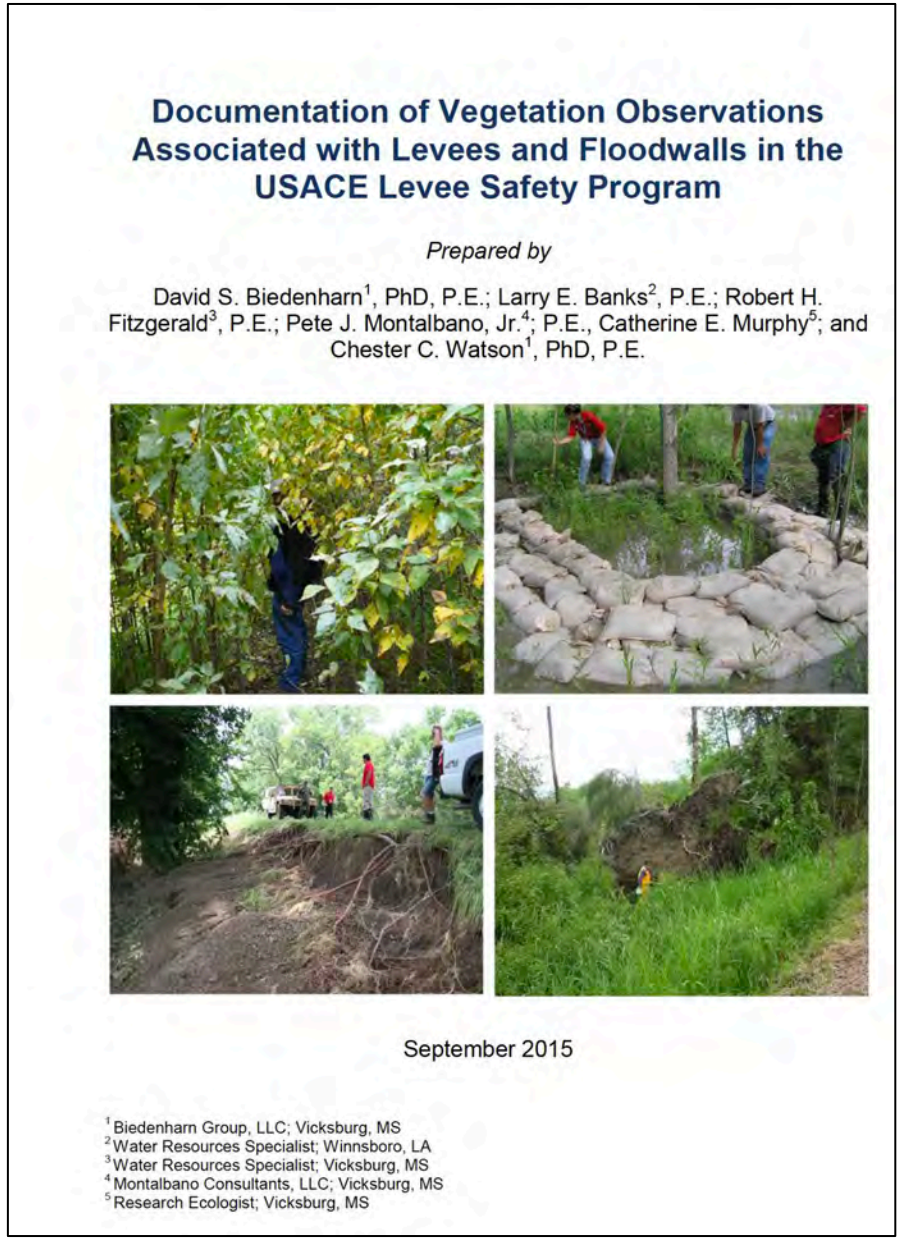
How do risk profiles for legacy and *de novo* vegetation compare?

Research synthesis report and addendum



One that I missed….

- A nationwide vegetation database was then developed using ratings and observations of impacts from the most recent Routine and Periodic Inspection Reports.
- Levee Embankments are present on 2,107 segments totaling about 11,497 miles in length.
- 61% of the levee embankment segments had unacceptable ratings in inspections for unwanted vegetation growth.
- Operational (17% of segments): inspection, access, maintenance, floodfighting
- Functional (3.9% of segments): damage to sod cover (0.9%), stability (e.g., overturned trees, slope stability, 1.5%), structural issues (cracked pavement, etc., 2.0%) and seepage (1 observation, 0.05%)



Documentation of Vegetation Observations Associated with Levees and Floodwalls in the USACE Levee Safety Program

Prepared by

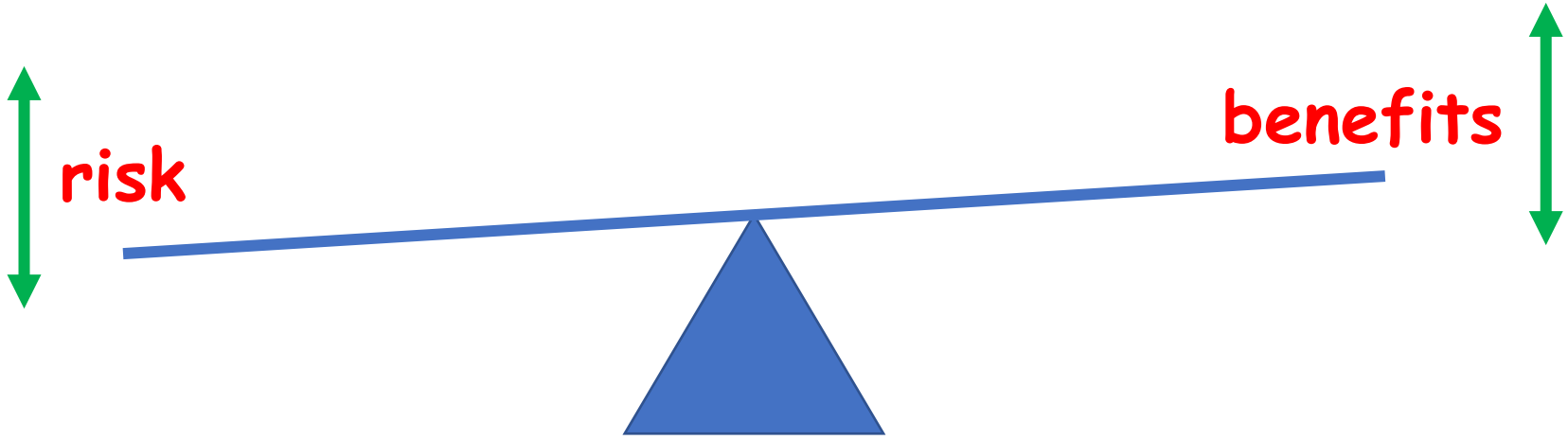
David S. Biedenharn[1], PhD, P.E.; Larry E. Banks[2], P.E.; Robert H. Fitzgerald[3], P.E.; Pete J. Montalbano, Jr.[4]; P.E., Catherine E. Murphy[5]; and Chester C. Watson[1], PhD, P.E.

September 2015

[1] Biedenharn Group, LLC; Vicksburg, MS
[2] Water Resources Specialist; Winnsboro, LA
[3] Water Resources Specialist; Vicksburg, MS
[4] Montalbano Consultants, LLC; Vicksburg, MS
[5] Research Ecologist; Vicksburg, MS

New questions

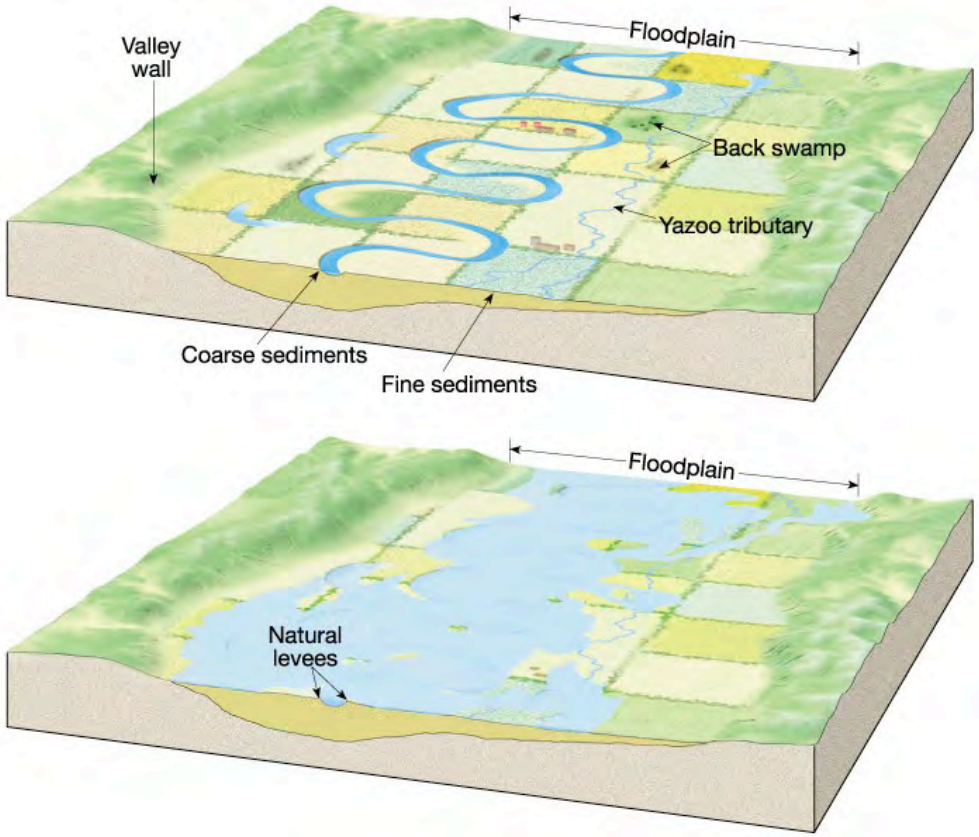
- What are the natural and beneficial functions of floodplains?
- How are these functions effected by levees?
- How are levee impacts mediated by woody vegetation?

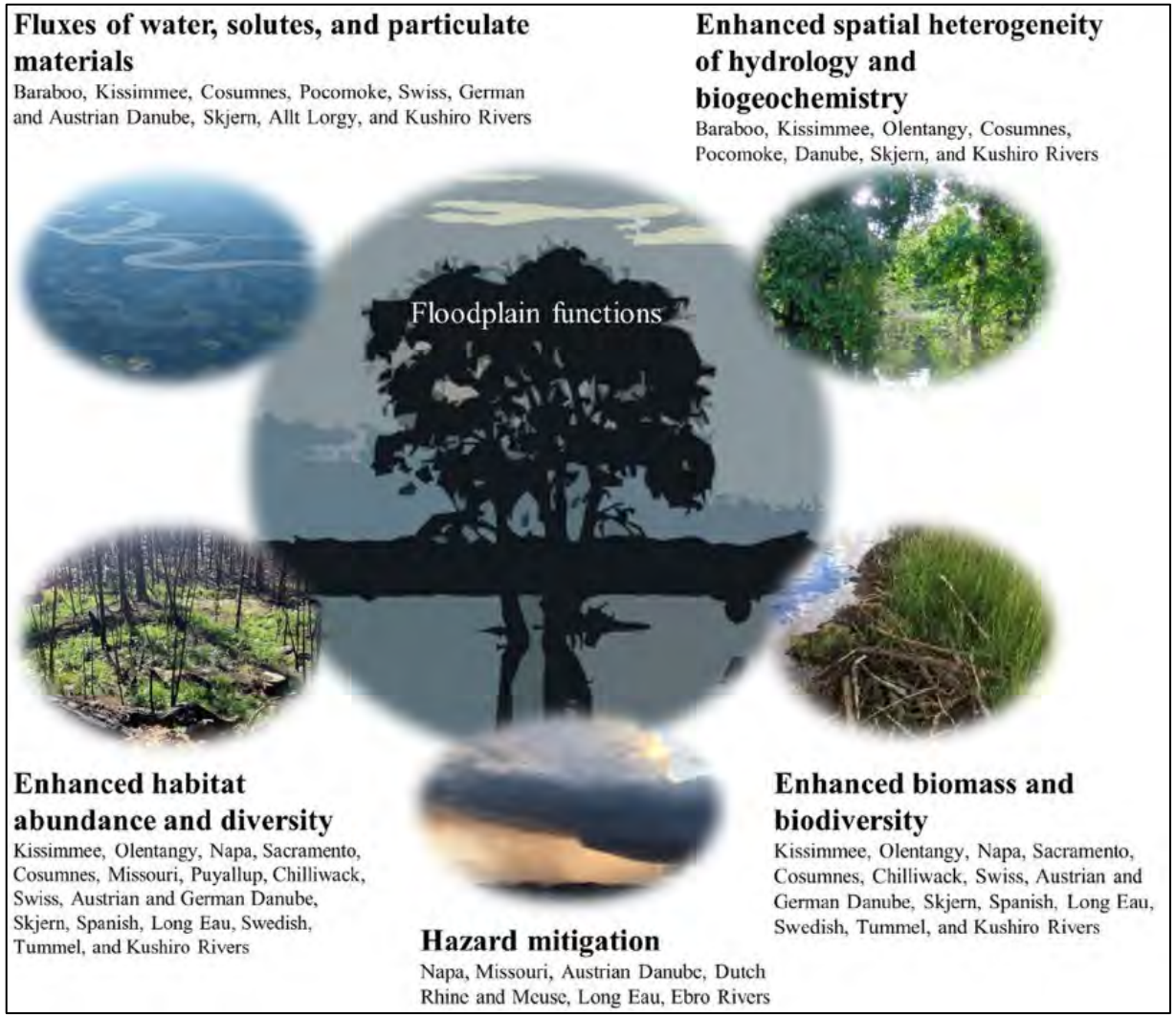


Floodplain functions

And how they are affected by levees

Functions of floodplains with hydrologic connection to stream

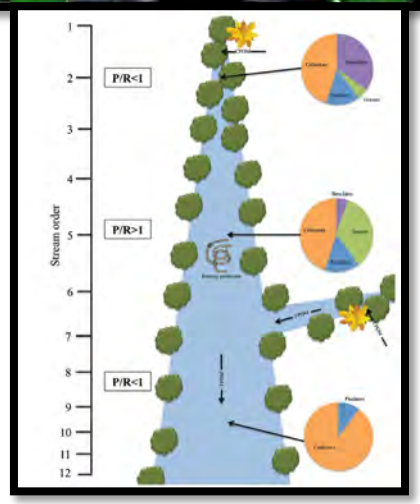




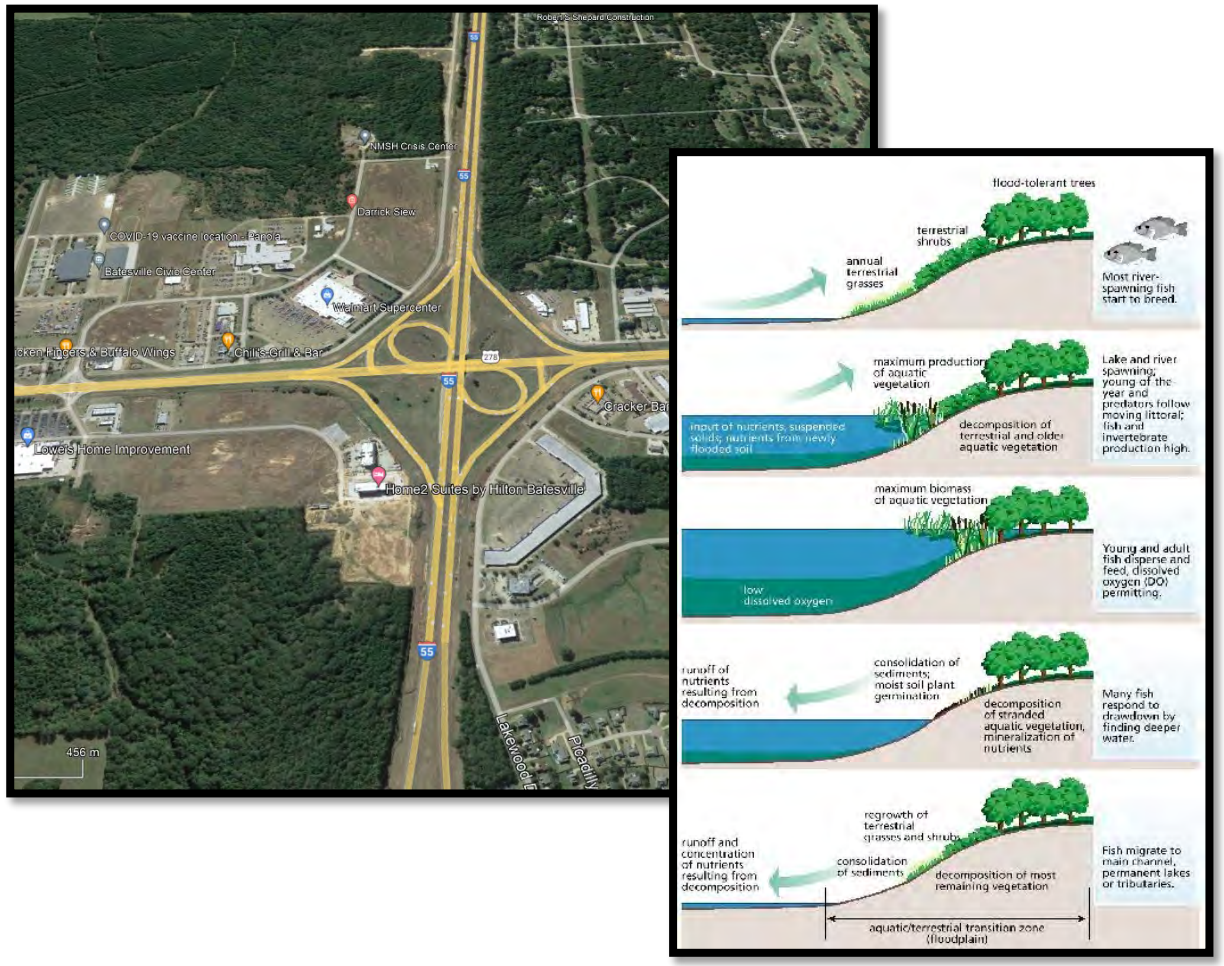
Knox, R. L. et al. 2022

Two views of riverine ecosystems

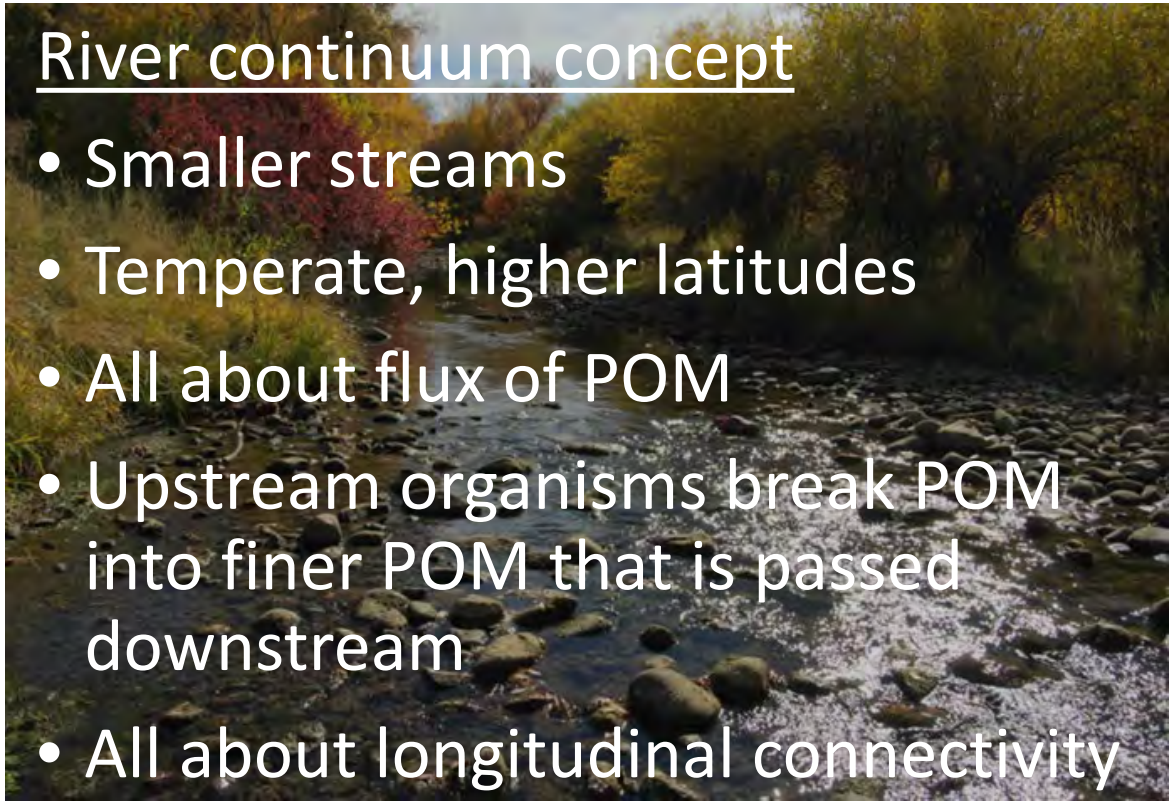
The river continuum concept (Vannote et al. 1980)



The flood pulse concept (Junk et al. 1989)

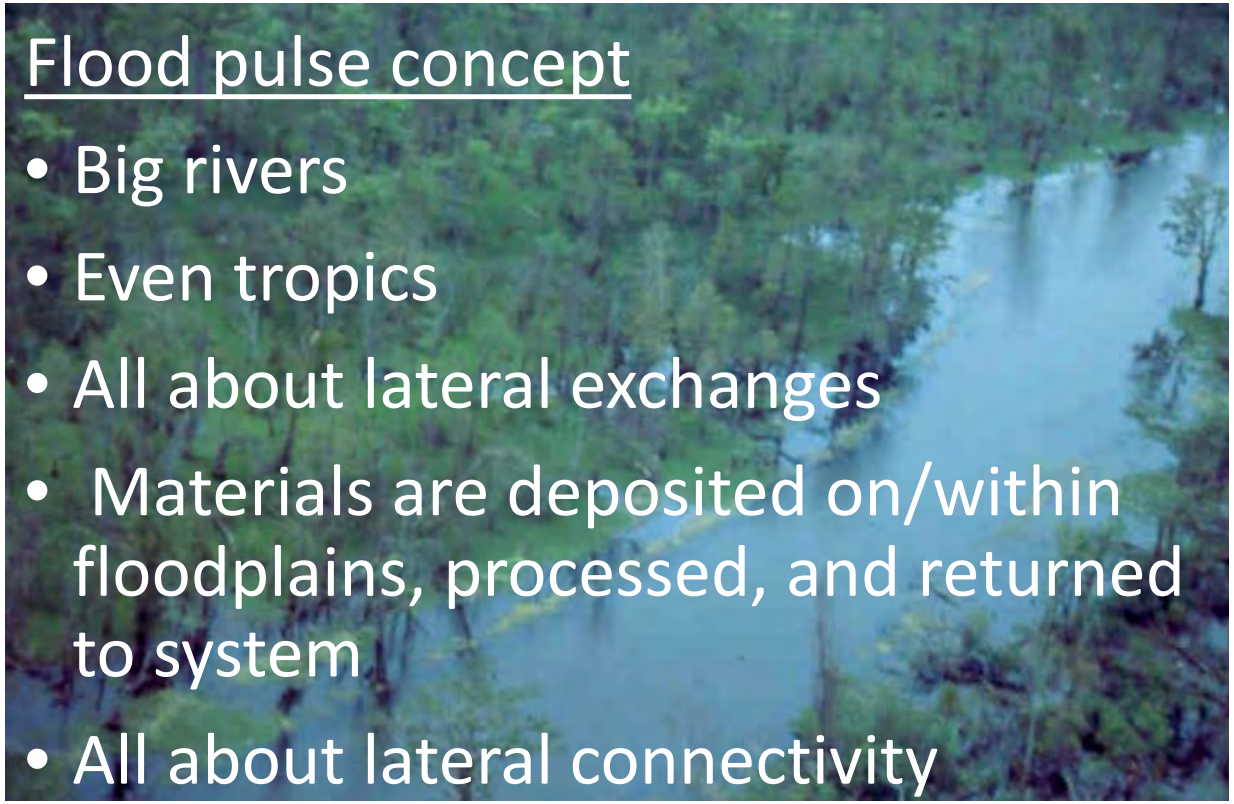


An engineer's view……



River continuum concept

- Smaller streams
- Temperate, higher latitudes
- All about flux of POM
- Upstream organisms break POM into finer POM that is passed downstream
- All about longitudinal connectivity



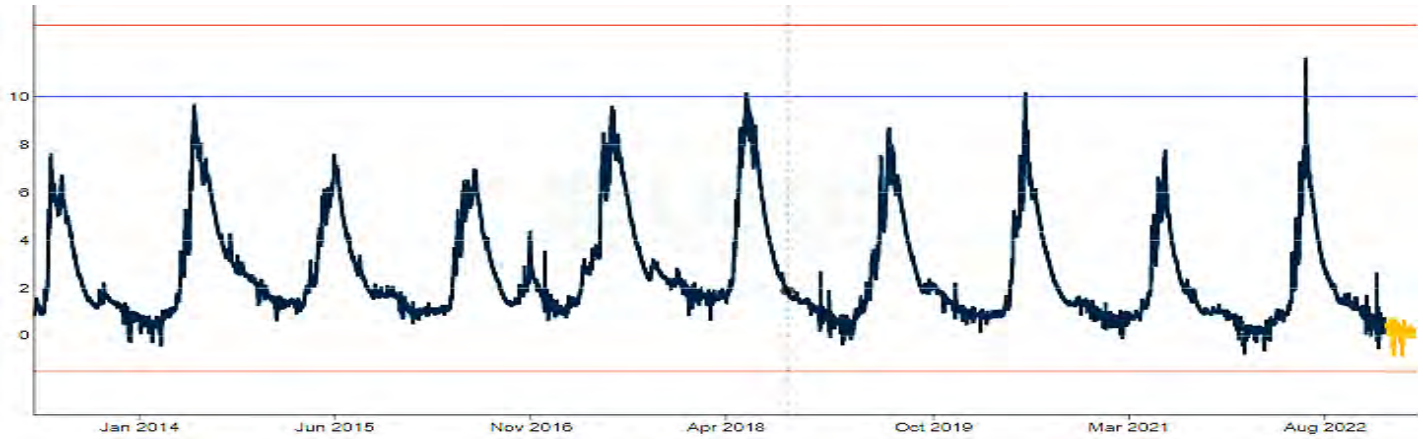
Flood pulse concept

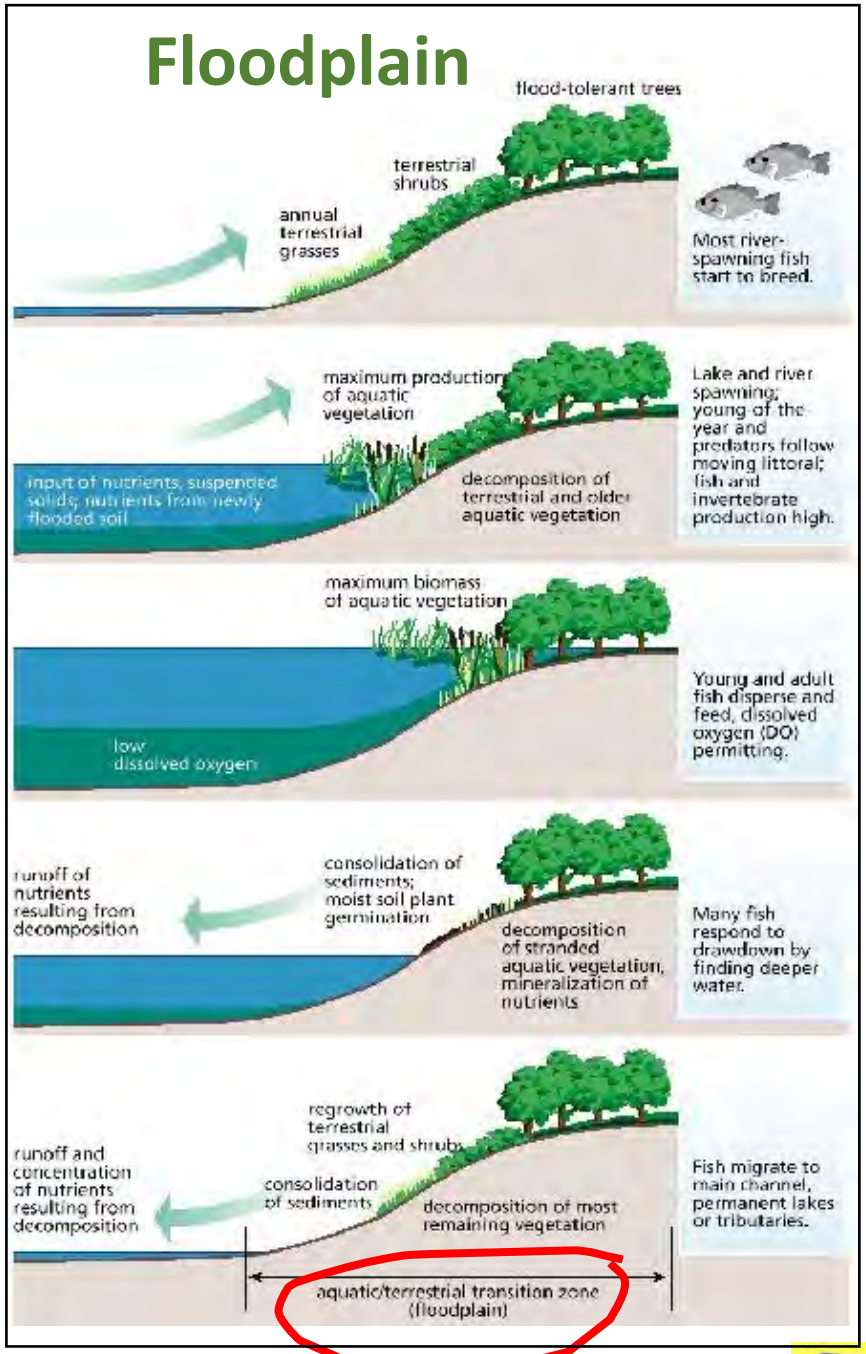
- Big rivers
- Even tropics
- All about lateral exchanges
- Materials are deposited on/within floodplains, processed, and returned to system
- All about lateral connectivity

The flood pulse concept

Junk et al. 1989

- Advance and retreat of floodwaters across riverine floodplains is key component of floodplain ecology.
- Aquatic terrestrial transition zone is most valuable habitat for many organisms.
- Regular rise and fall of floodwaters also produces key physical and chemical processes.



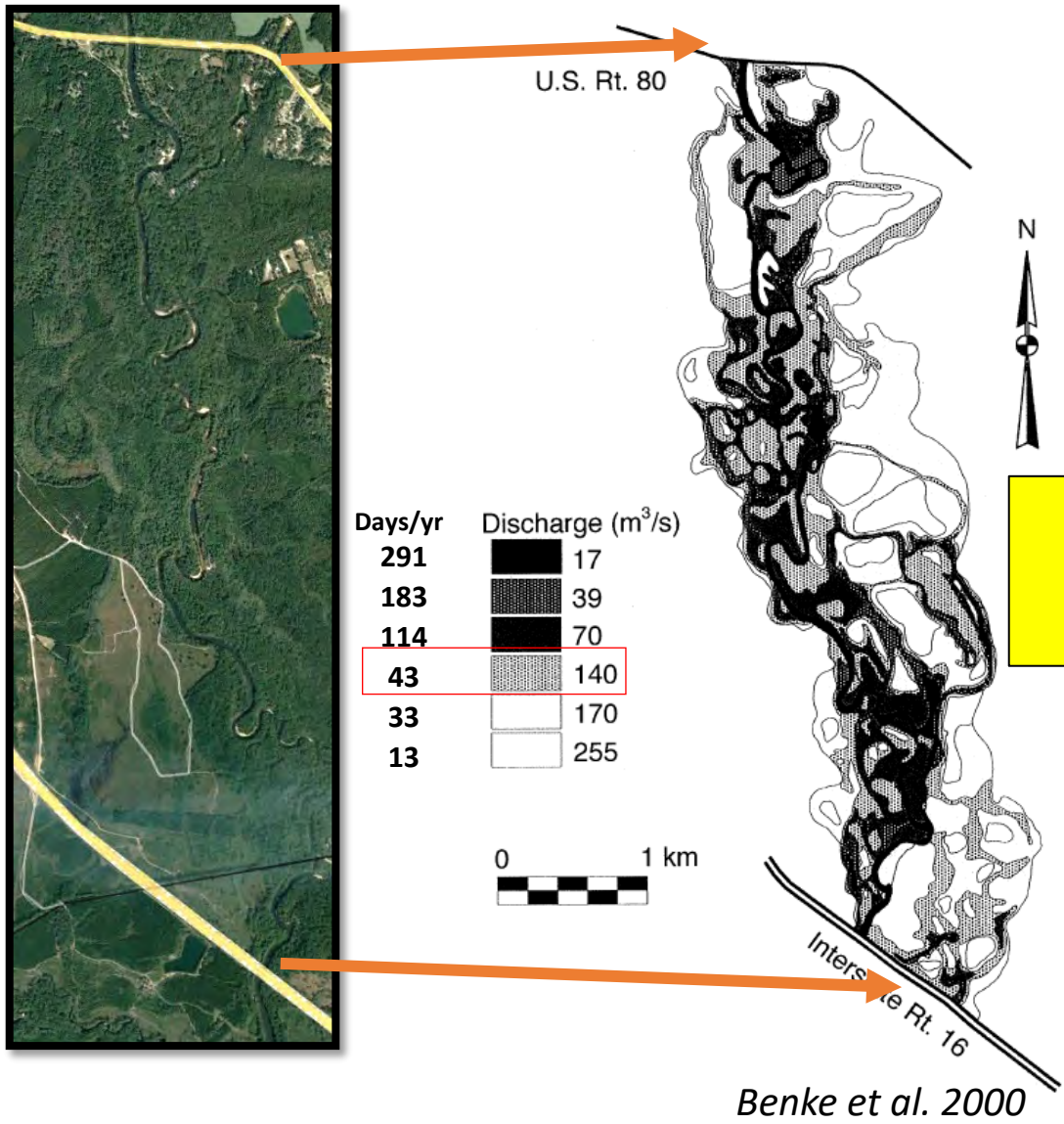


Along many rivers, the frequency and duration of flood pulse can be surprising.

Jan 2007

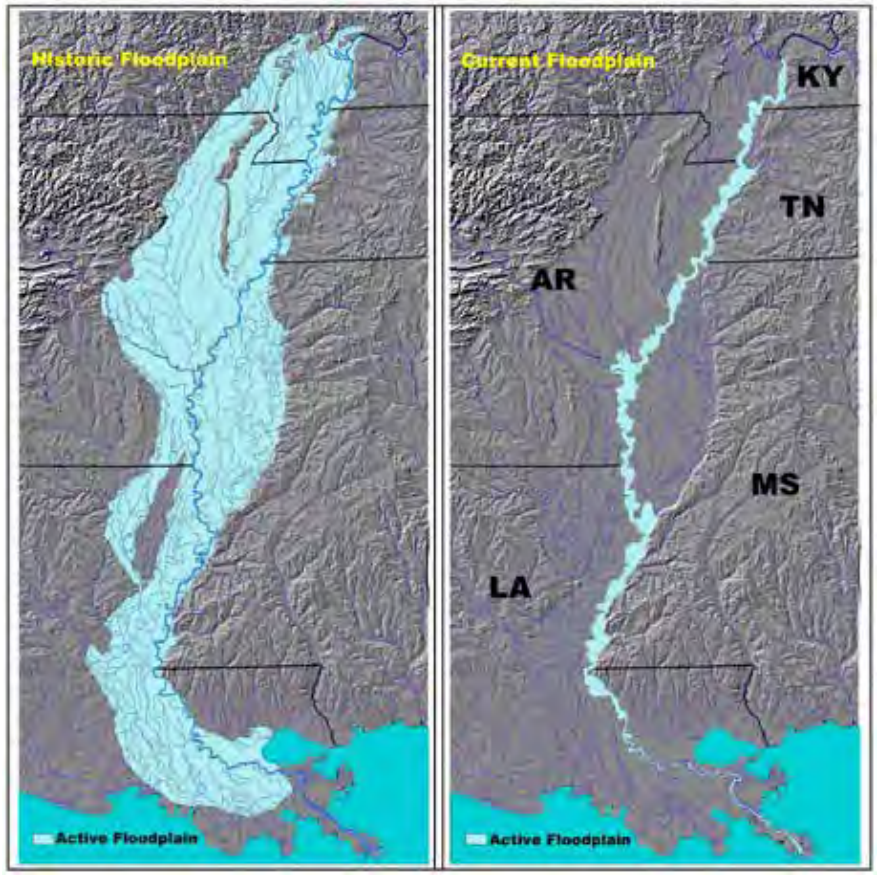
Dec 2020

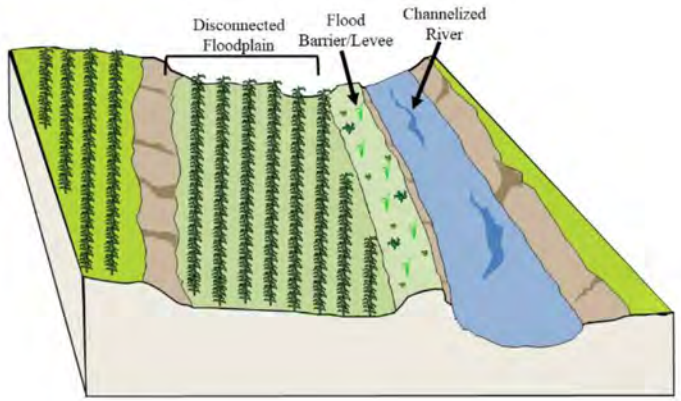
Ogeechee River, Georgia



Benke et al. 2000

By the 1990s, an estimated 90% of the entire Mississippi River floodplain had been disconnected from the main channel due to levee construction and up to 90% of floodplains across North America are cultivated and thus have lost most, if not all, ecological functionality. In the Upper Mississippi River Basin alone, there are over 8,000 miles of known levees disconnecting floodplains from their river channels.





Gordon et al. 2020

Benefits of floodplains

“the natural and beneficial functions of floodplains…”

Benefits of hydrologically connected floodplains

- Storm surge attenuation (coastal zones)
- Flood and erosion control
- Water quality maintenance
- Groundwater recharge

Water resources

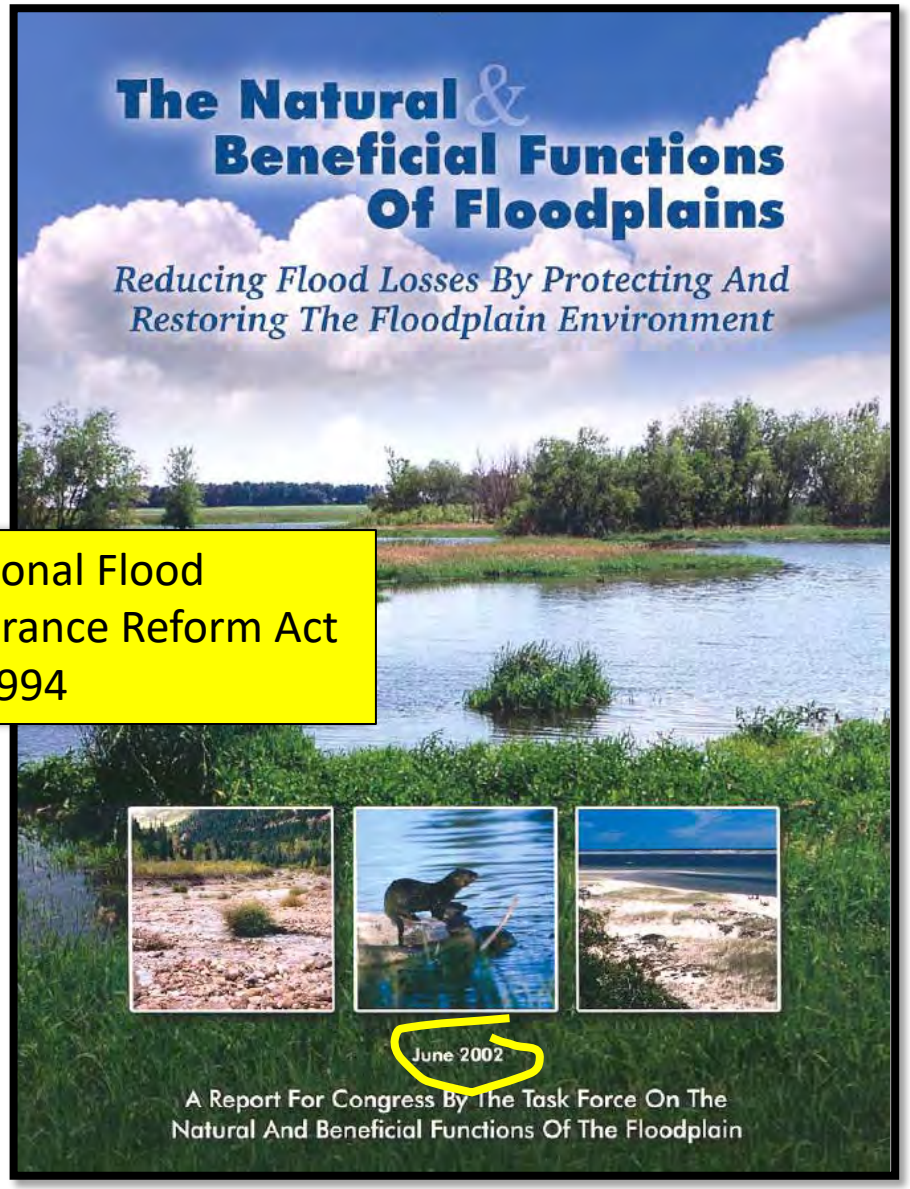
- Biological productivity
- Biodiversity
- Fish and wildlife habitat

Biological resources

- Agriculture and silviculture
- Recreation
- Aesthetic resource
- Cultural resources
- Research

Societal resources

National Flood Insurance Reform Act of 1994



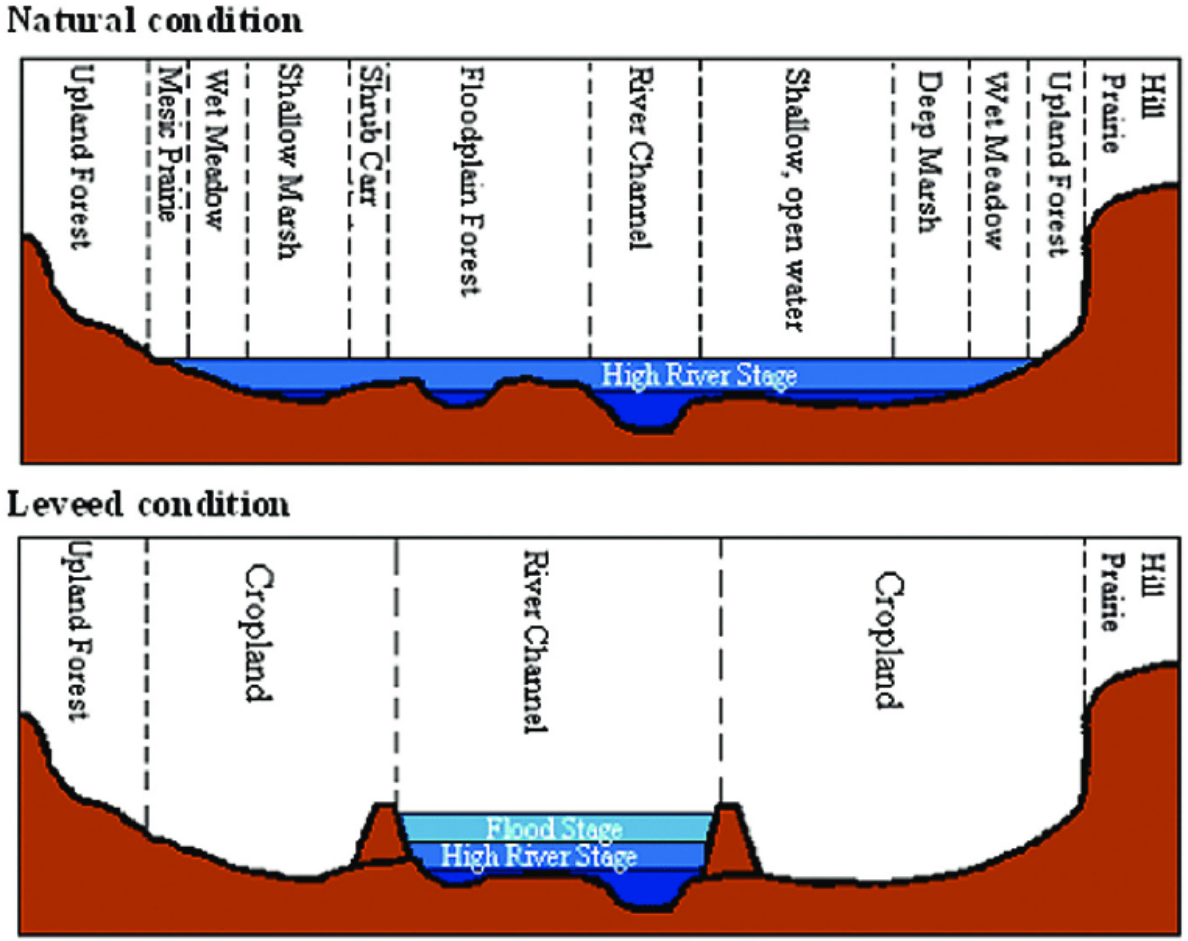
Four key attributes for floodplain benefits

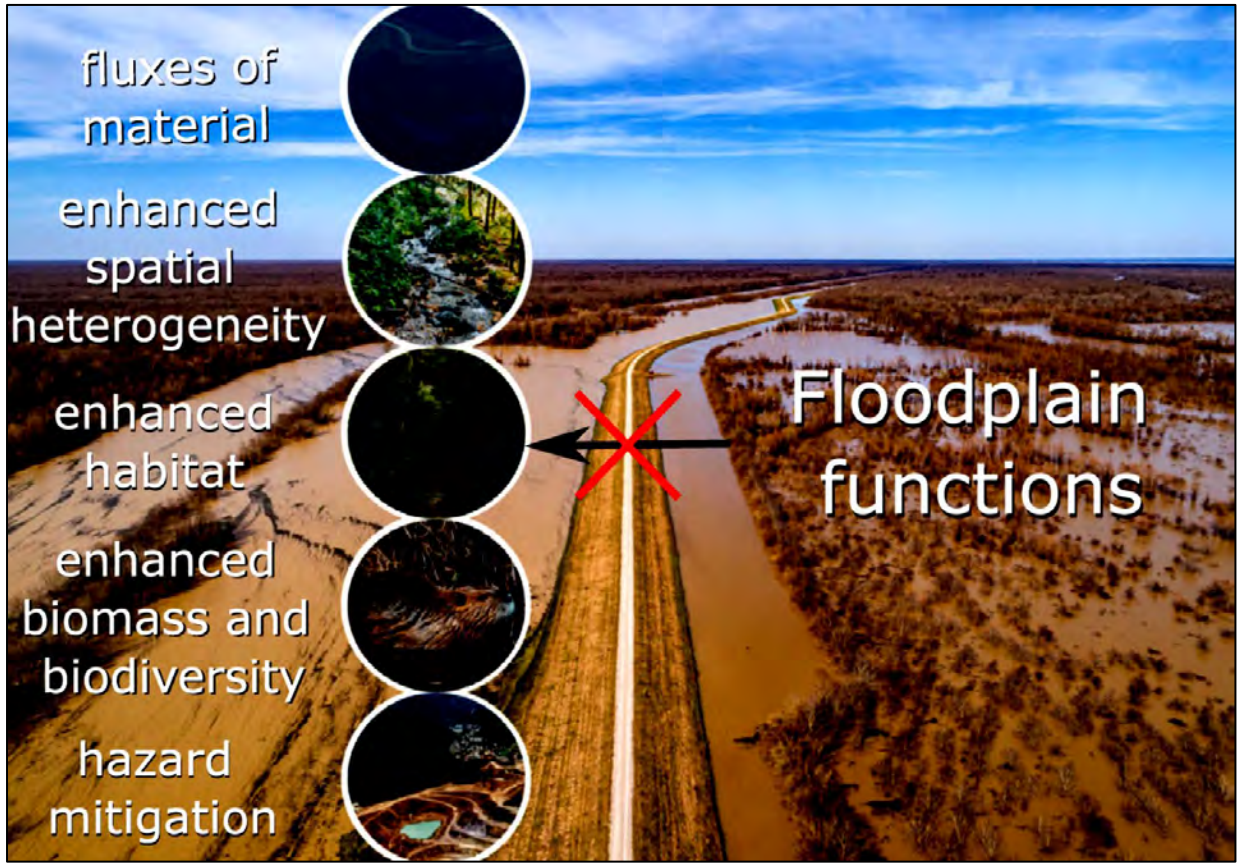
- Connectivity
  - Water, sediment, nutrients, organisms
- Hydrologic variability
  - Inundation varies in timing, duration, magnitude, and frequency in a way that supports native biota
- Spatial scale
  - Large enough to support habitat and landscape forming processes
- Habitat and structural diversity
  - Diversity of physical conditions—sediments, moisture, vegetative succession, debris accumulation…..

Effects of levees on floodplain functions

“Ecosystem services,” maybe…

Effects of levees on floodplain function





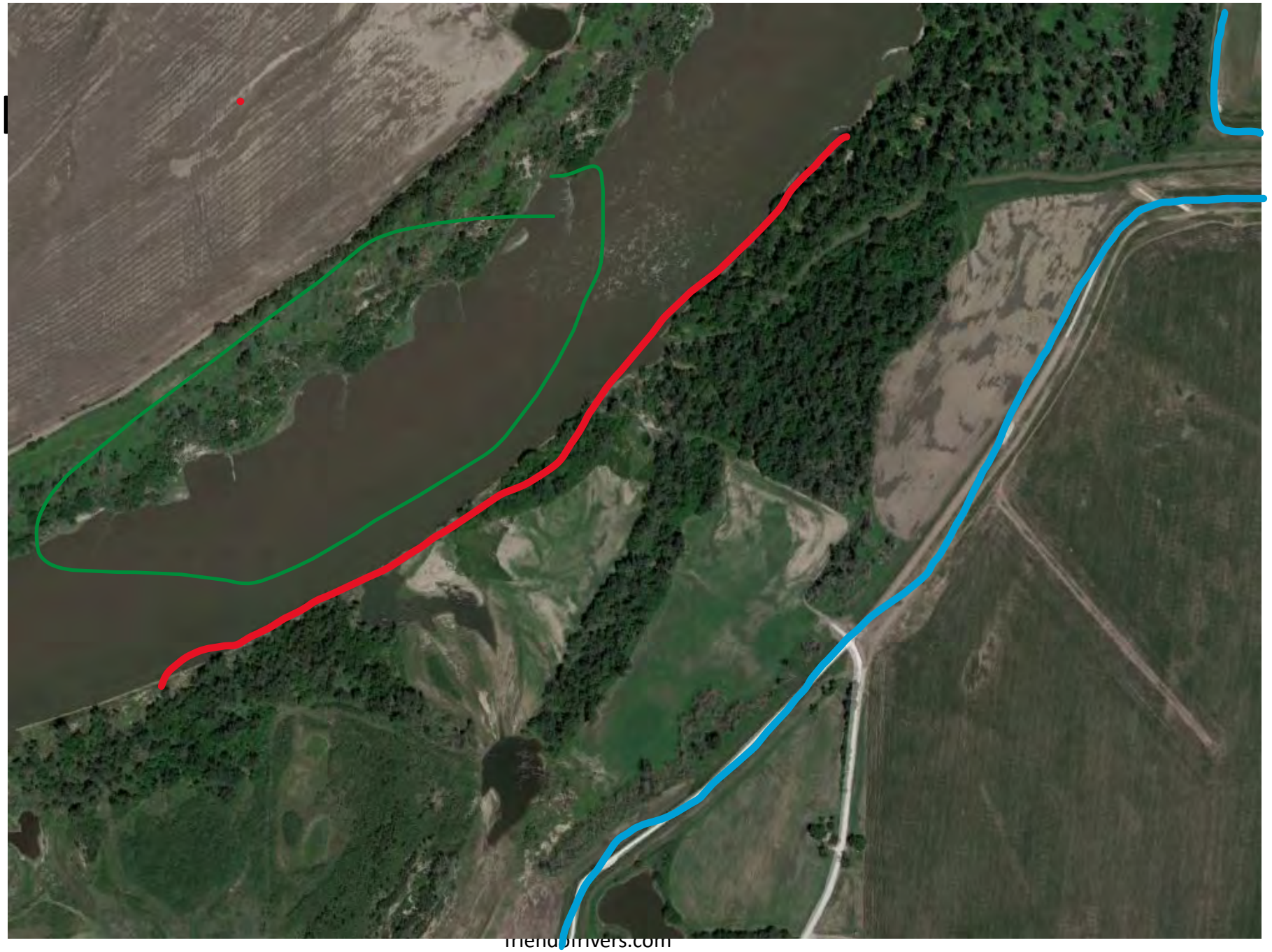
Knox, R. L. et al. 2022

Levees usually necessitate channel stabilization

River	River km	Impact on habitat	Impact on fishery
Mississippi	0-1570	River length shortened 229 km. Floodplain reduced by 90% by levees	Unknown
Missouri	0-1811	River length shortened 320 km. Water area reduced 34-66%. 2,111 km^2 natural habitat lost from channel and meander belt.	Commerical fish harvest reduced by 80% in reach within state of Missouri.
Sacramento	0-311	Freshwater wetland vegetation acreage in valley reduced by 43% between 1939 and mid-1980s.	Mean fall-run chinook salmon numbers upstream of Rkm 391 reduced 87% between 1950-1959 and 1980-1985.
Willamette	0-301	Fourfold decrease in surface water volume. Elimination of braided reaches. Removal of 550 snags per linear km.	Unknown
Rhine	0-1320	Backwaters, braids, and side channels greatly reduced. Bed degradation up to 7 m. Area subjected to flooding reduced 85-94%.	Continuous decline of catches since 1915
Vistula	0-640	Elimination of islands and braided reaches, particularly in the lower course of the river. Channel width reduced by 50%. Bed lowered 1.3 m (reach from Wloclawek Dam to Swiecie)	Sharp decline in commercial fish harvest, especially of migratory species.

Shields and Gore (1995)

Chan



Floodplain water bodies...a vanishing breed

- When channels are stabilized, no new floodplain waterbodies are formed by avulsions, cutoffs or lateral migration.
- Old water bodies gradually transition to terrestrial habitats due to sedimentation.

Levee vegetation

Alleviation of levee effects on floodplain function

Legacy trees on levees….why are they there?

- The age of the levee. Most levees were constructed many years ago. Some are hundreds of years old and, over time, vegetation has been allowed or its prohibition has not been enforced.
- Limitations of resources during times when levee maintenance is a low priority (e.g. in Europe during and post-WWII).
- Difficulties in accessing slopes with mechanical equipment.
- Encouragement of woody vegetation to provide additional erosion protection.
- Encouragement of woody vegetation for fisheries and habitat.
- Encouragement of woody vegetation for aesthetics and recreation.
- Beliefs that woody vegetation provides benefits that outweigh the risks.
- Concerns that removing existing woody vegetation may cause harm to levee integrity.

CIRIA 2013

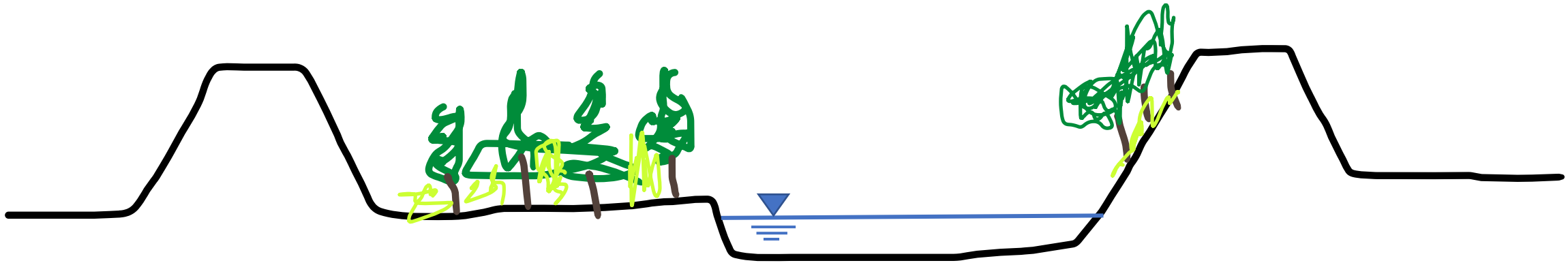
Two types of levee project woody vegetation

“basic levee”

- Floodplain (or berm) vegetation

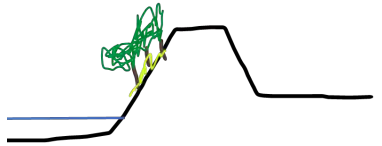
“bank levee”

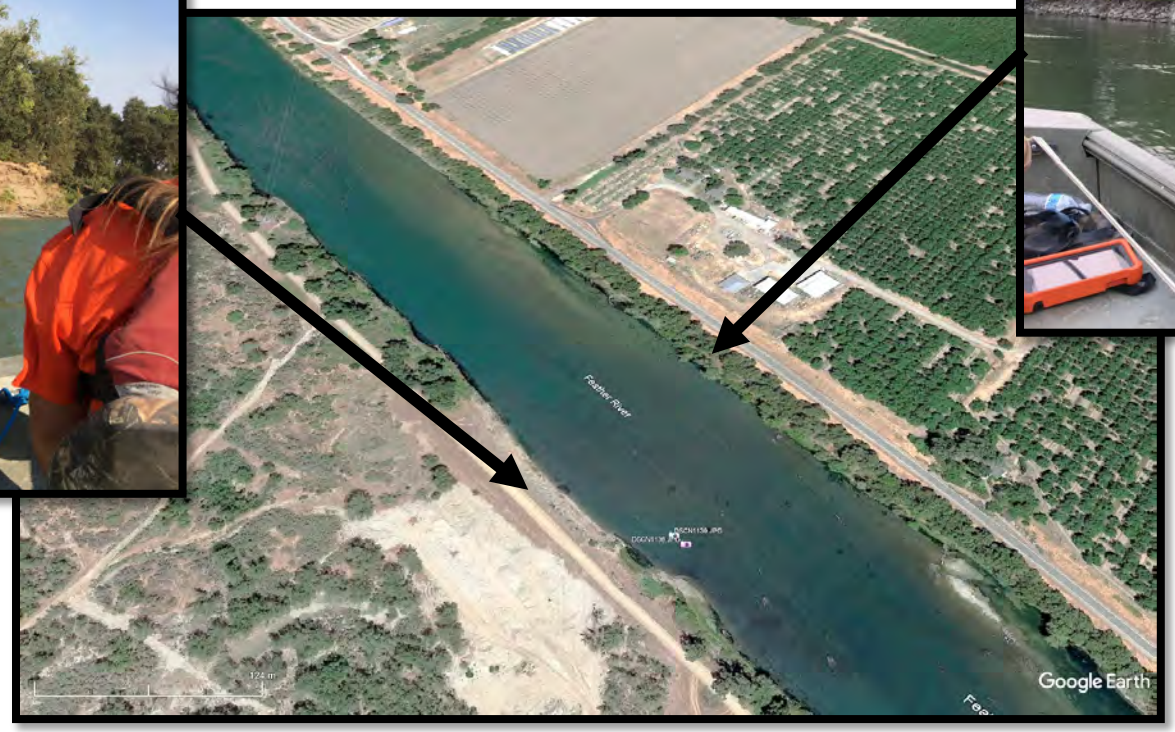
- Bank vegetation



Two types of floodplain vegetation

Two types of bank vegetation





Floodplain functions and levee vegetation

- Storm surge attenuation (coastal zones)
- Flood and **erosion control**
- **Water quality maintenance**
- Groundwater recharge

Water resources

- Biological productivity
- Biodiversity
- **Fish and wildlife habitat**

Biological resources

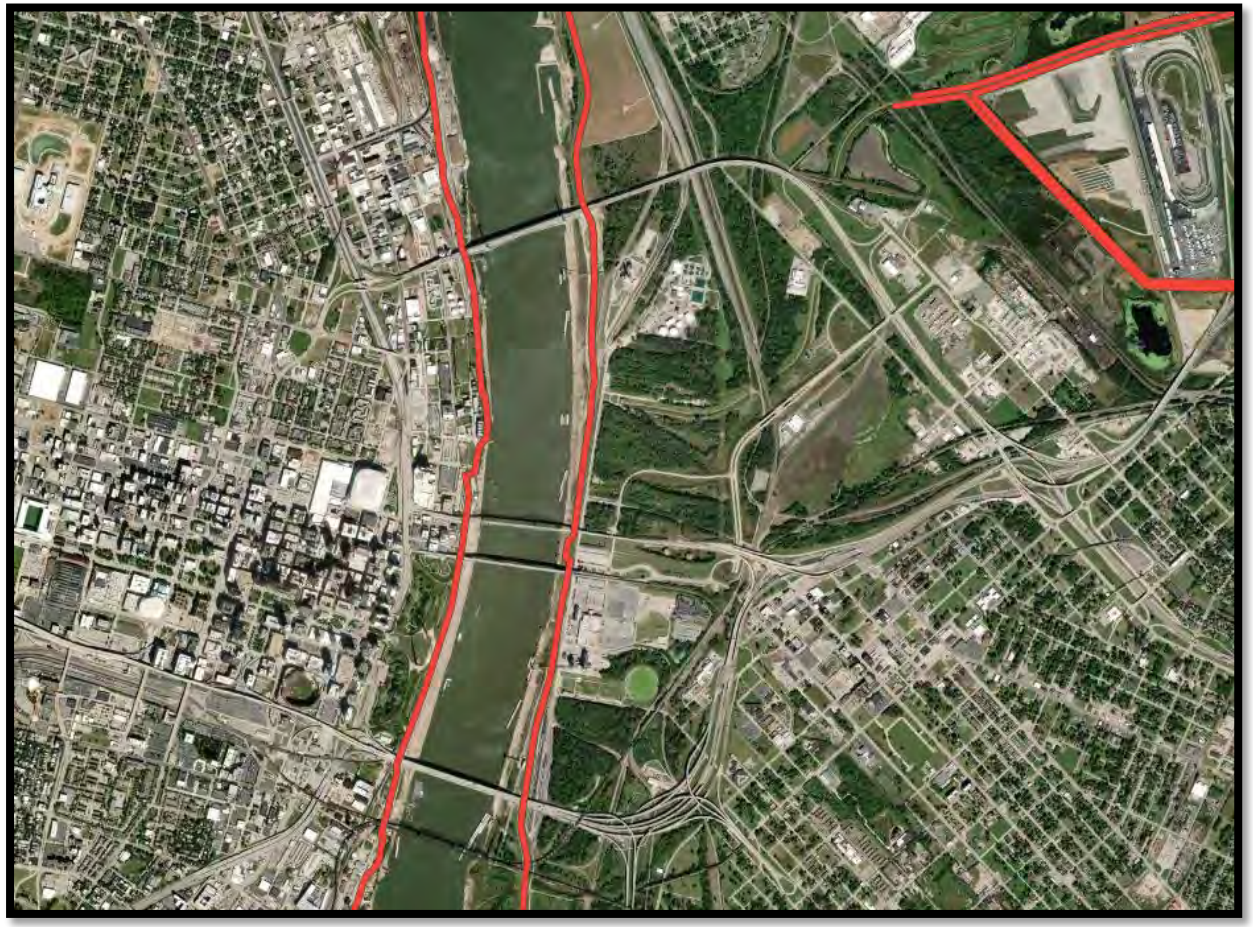
- Agriculture and silviculture
- Recreation
- Aesthetic resources
- Cultural resources
- Research

Societal resources

The Cadillac (Tesla?).....levee setback

Setbacks often not feasible

St. Louis/East St. Louis



Kansas City

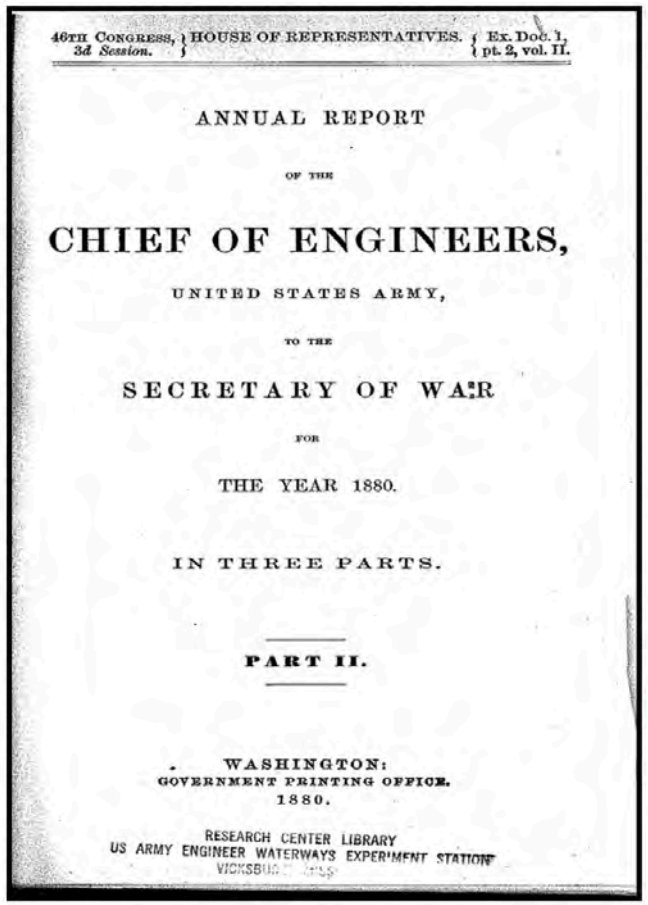
Erosion control

Effects of woody vegetation on floodplains and banks

Water erosion processes on levees

- Sheet erosion/rilling
- Fluvial erosion
- Wave wash
- Overtopping
- Local scour
- Piping
- Geotechnical slope failure (not strictly water erosion, but facilitated by it)

Early observations on Mississippi River



46TH CONGRESS, 3d Session. } HOUSE OF REPRESENTATIVES. { Ex. Doc. 1, pt. 2, vol. II.

ANNUAL REPORT

OF THE

CHIEF OF ENGINEERS,

UNITED STATES ARMY,

TO THE

SECRETARY OF WAR

FOR

THE YEAR 1880.

IN THREE PARTS.

PART II.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1880.

Annual Report of the Chief of Engineers, 1880

"One of the most important developments of this survey is the evidence which present position of the shore lines affords, that the stability of the banks has decreased with the settlement of the country and the clearing away of the forests…

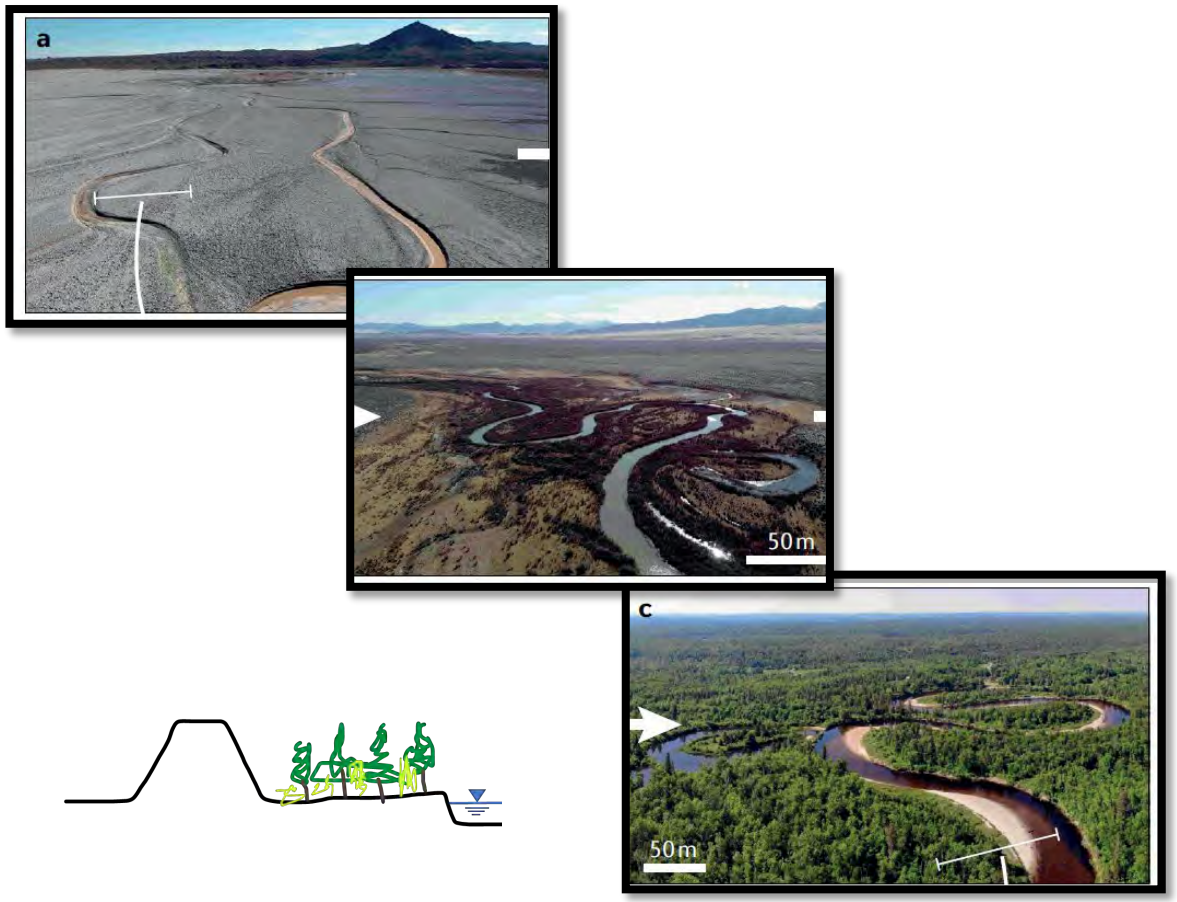
An examination of the shore line shows that in every case where cleared fields along a caving bank are interrupted by a patch of woods the latter projects out into the river. It is easy to believe that the binding quality of the roots, and protection formed by the fallen trees at the foot of the bank should have this effect…"

O H. Ernst, Captain of Engineers

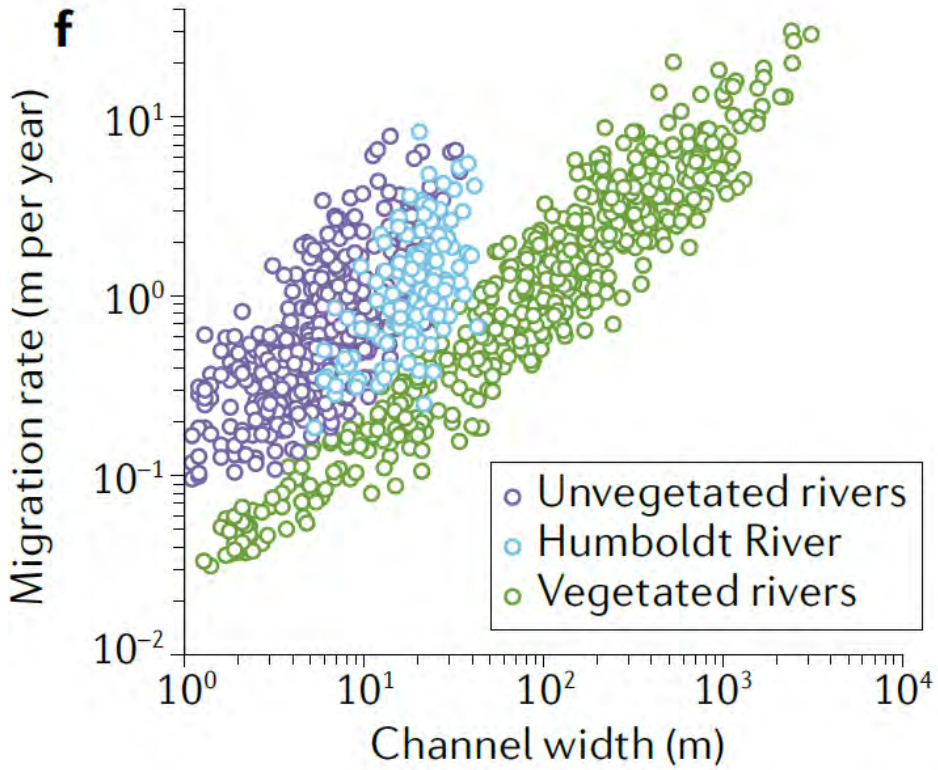
"The greater stability of the bank stocked with trees over those cleared for cultivation is observable everywhere along the river…"

J. H. Simpson, Colonel of Engineers

Lateral migration rates slower for vegetated floodplains



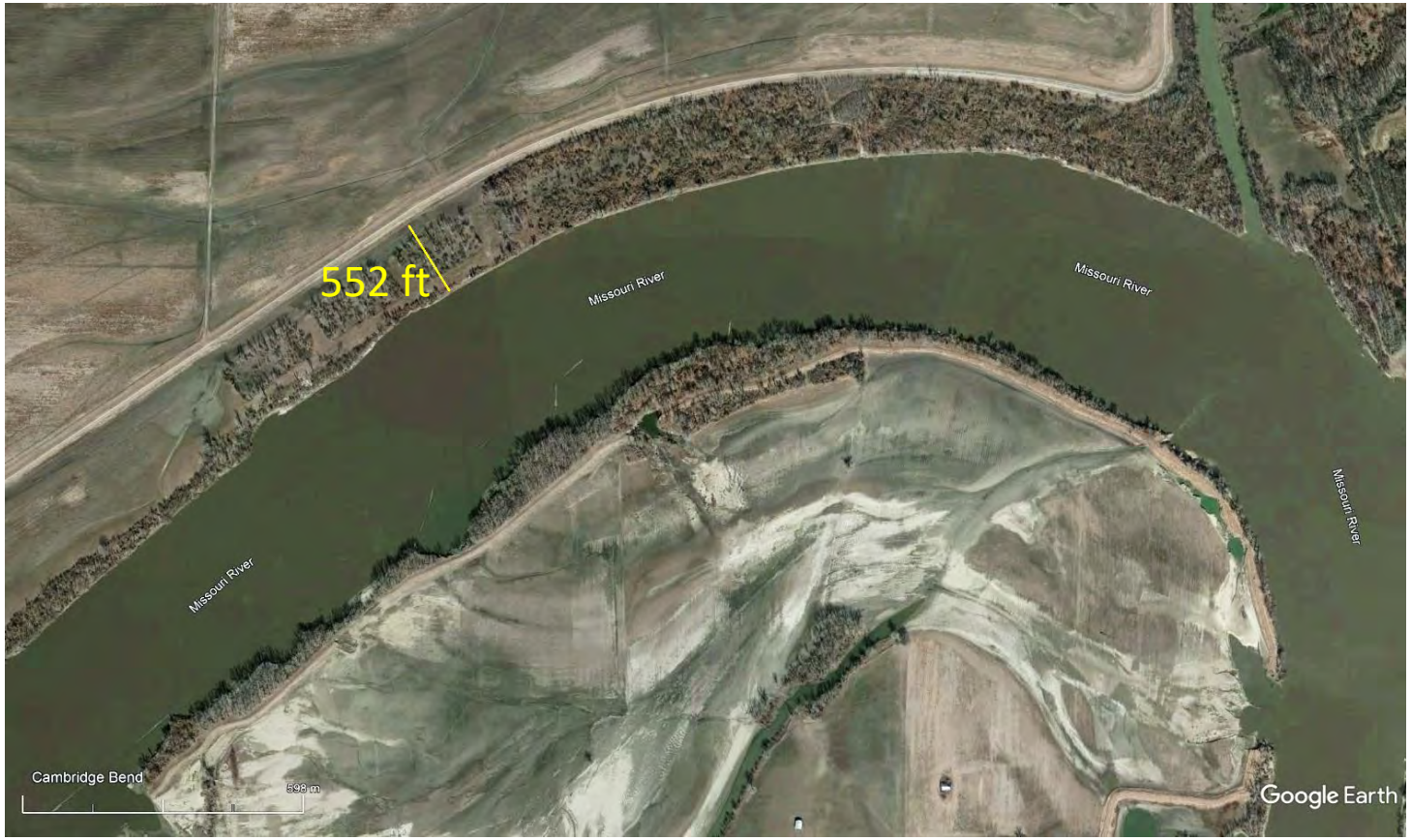
Meandering rivers



Ielpi et al. 2022

Levee vegetation and erosion control

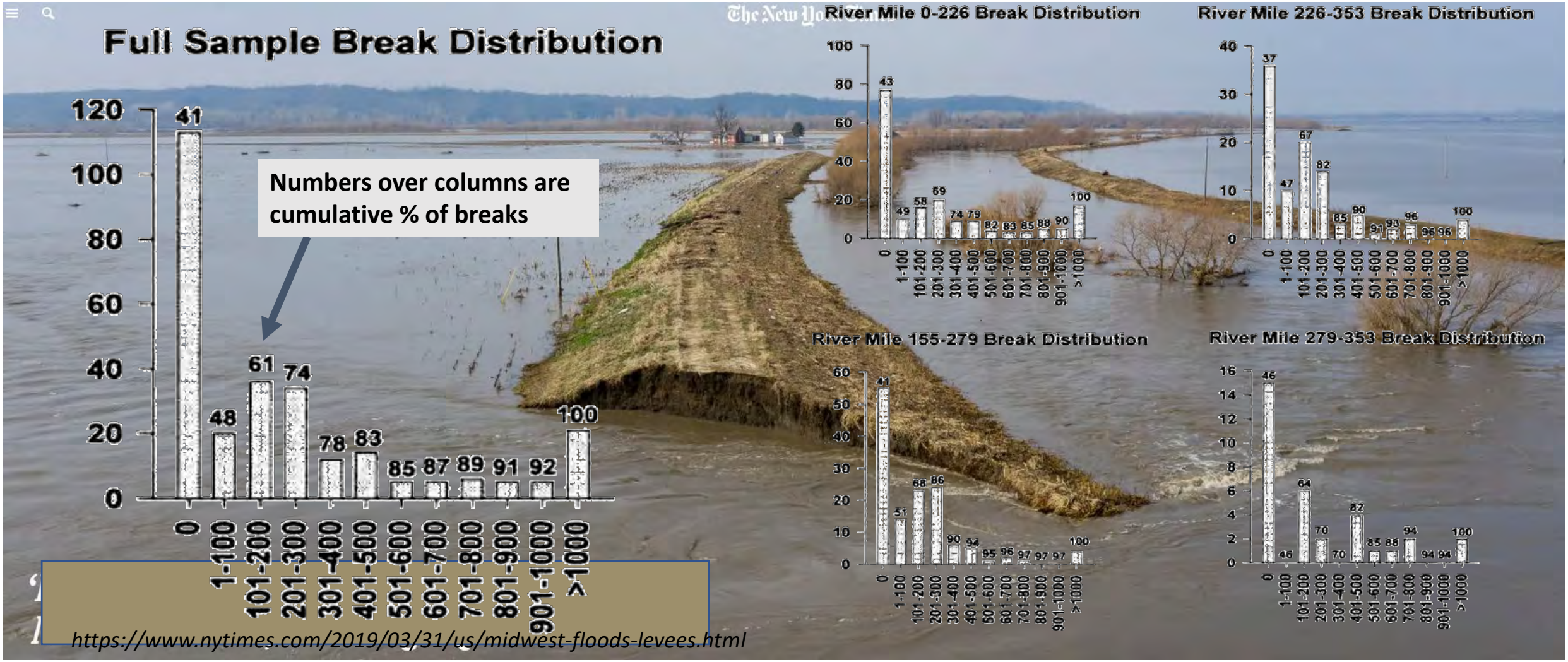
Frequency and length of Missouri River levee breaks during 1993 flood were controlled by presence and width of **woody corridor.**



Allen et al. 2003

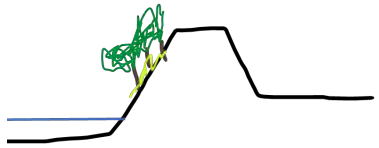
Woody corridor width and levee break frequency Missouri River, 1993 flood

Allen et al. 2003

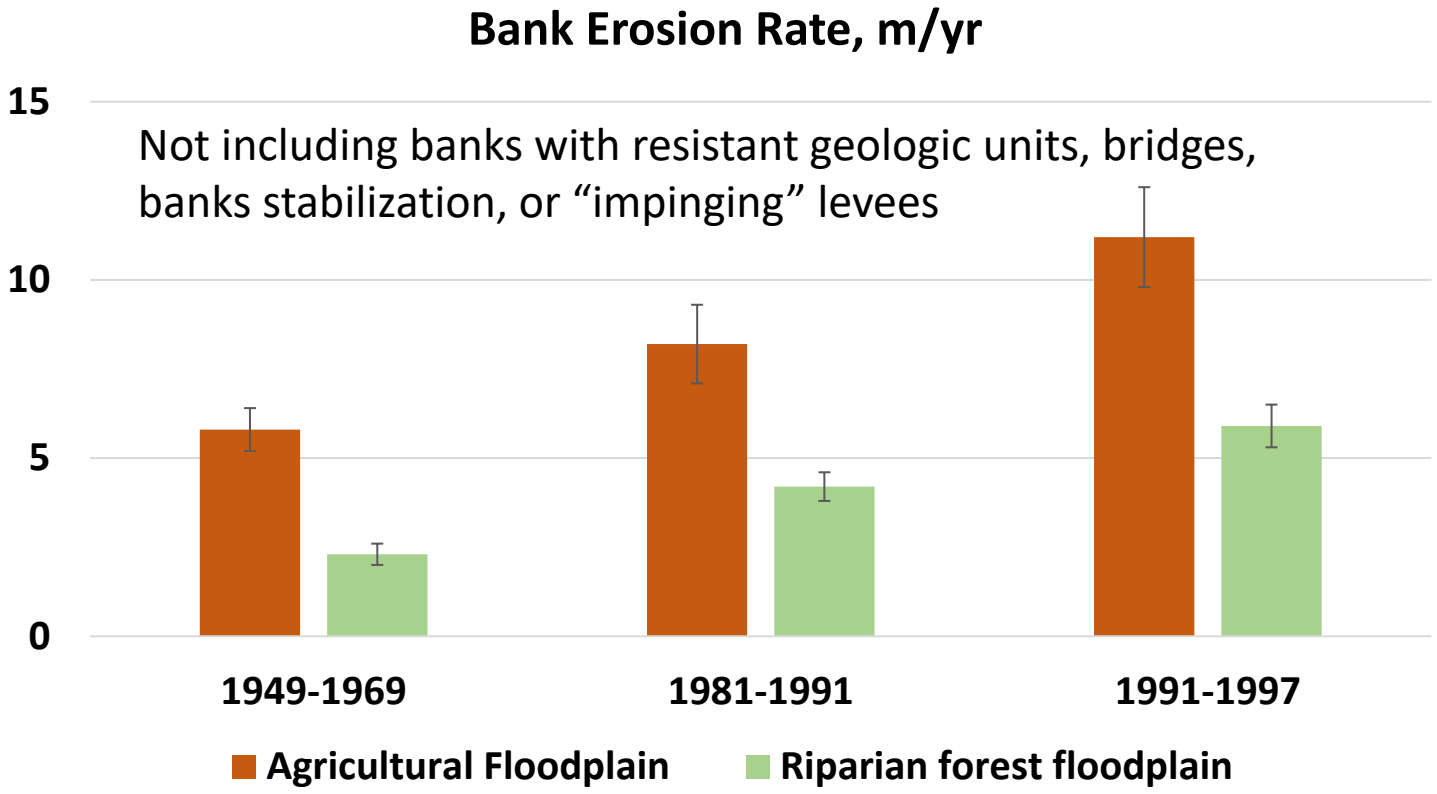


https://www.nytimes.com/2019/03/31/us/midwest-floods-levees.html

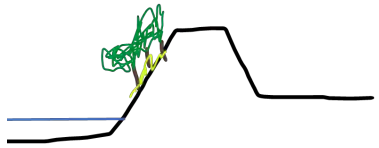
Levee vegetation and erosion control



Micheli et al. (2004) found Sacramento River lateral migration rates were greatly reduced for banks with woody vegetation as opposed to agricultural land use.



Levee vegetation and erosion control



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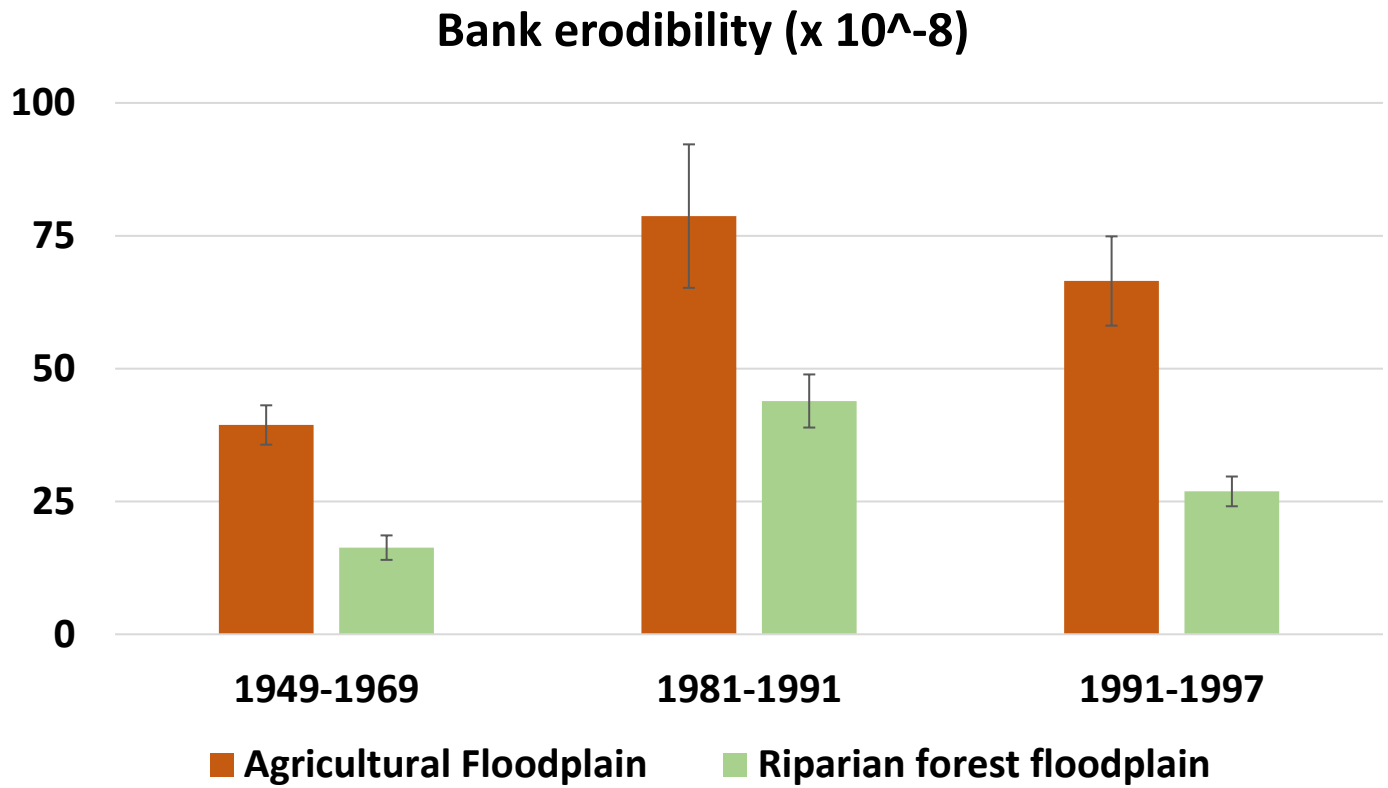
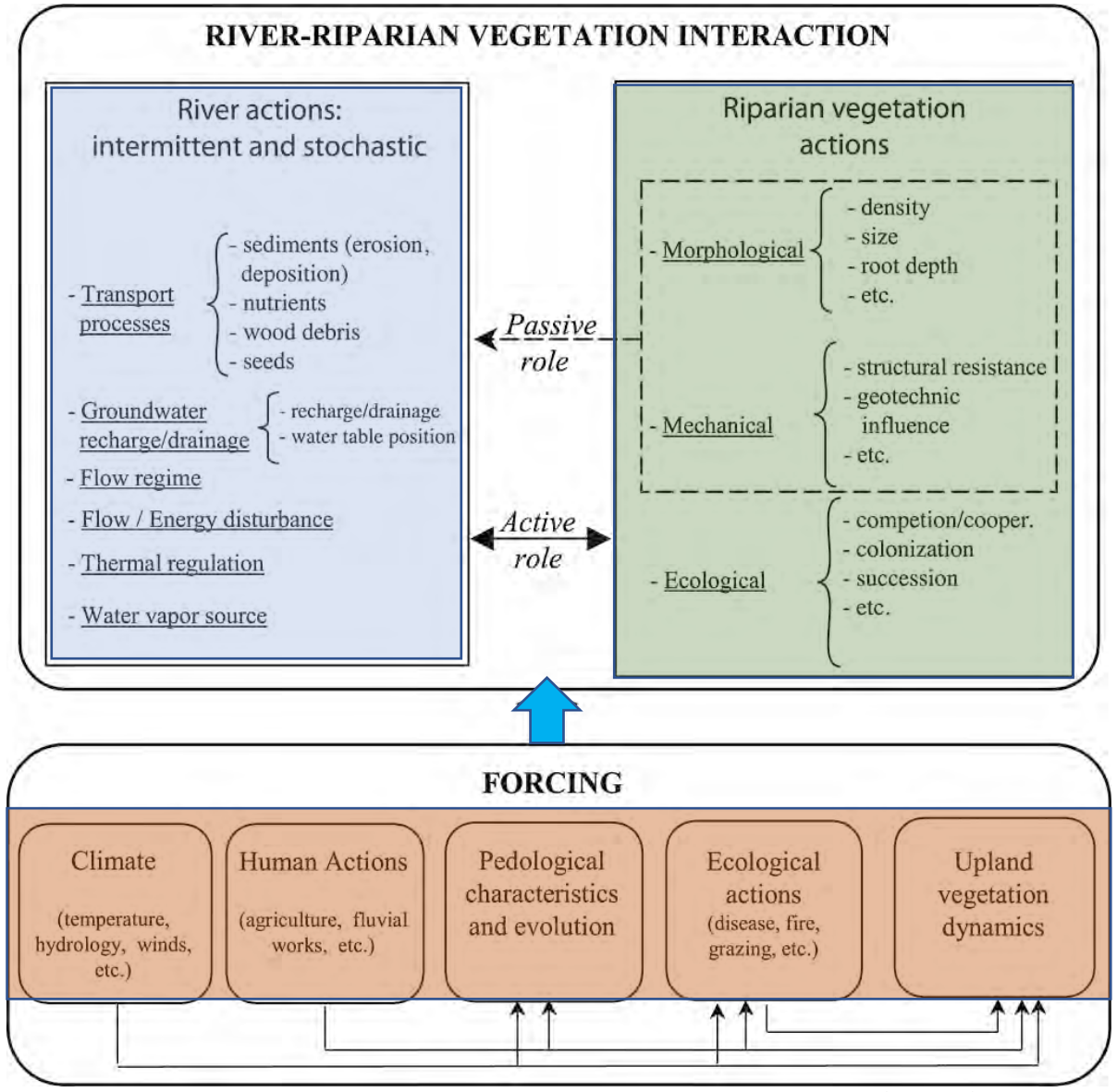


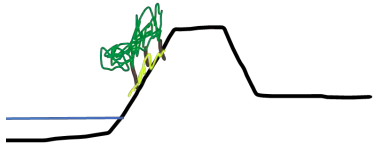
However, please note….

The interaction between river morphology and riparian vegetation is quite complex.



Camporeale et al. 2013

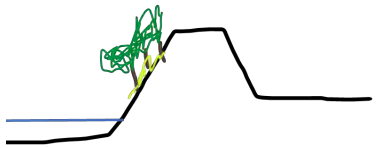
Wave wash erosion

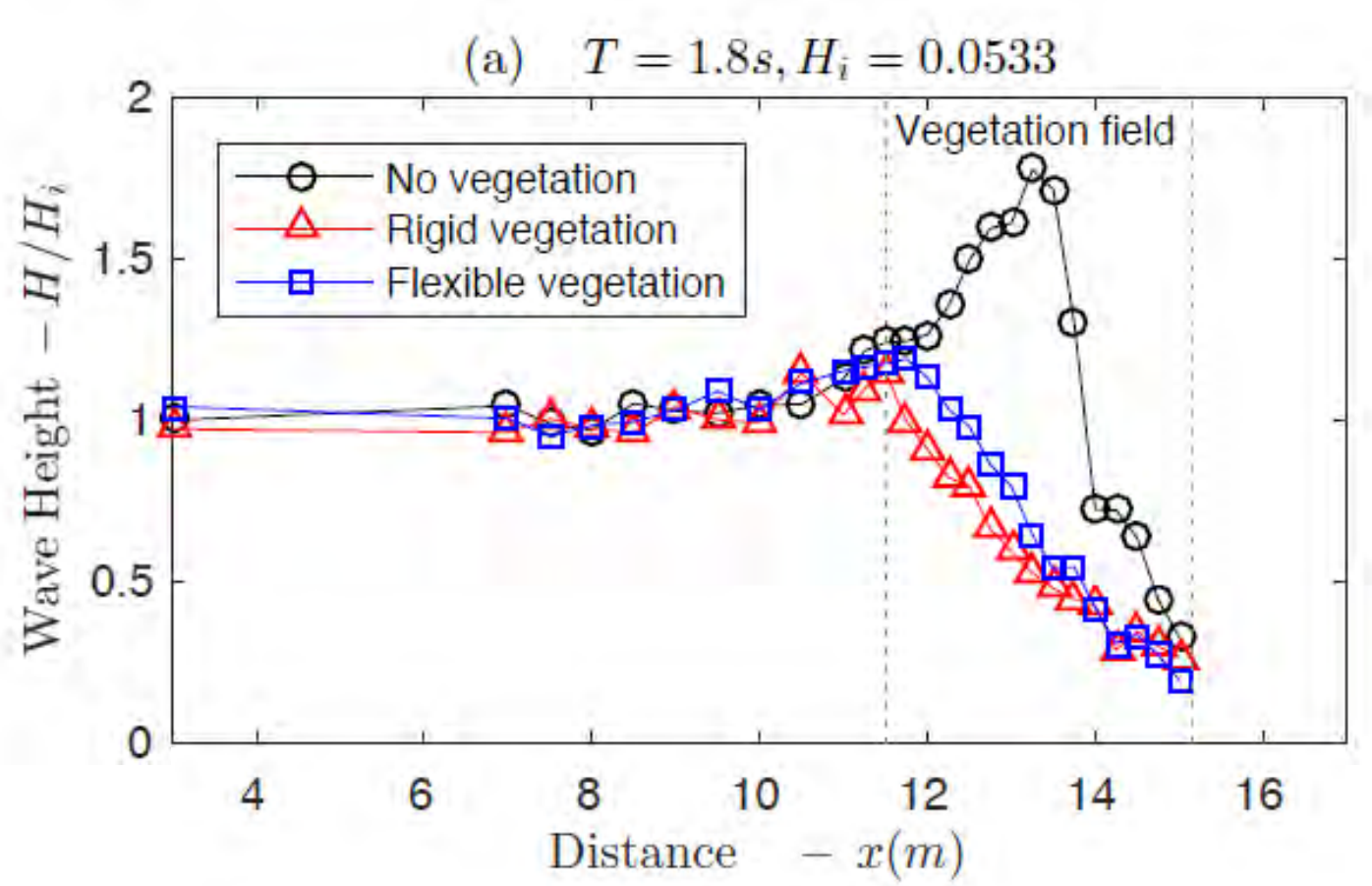


Woody species on waterside slope/at toe

- “Brush and small trees may be retained on the waterward slope where desirable for the prevention of erosion and wave wash. Where practicable, measures shall be taken to retard bank erosion by the planting of willows or other suitable growth on areas riverward of the levees.” (USACE 1949)
- “…in-place riparian habitat serves as a protective buffer between the levee and erosive flows.” (Draft EM 1110-2-1913)

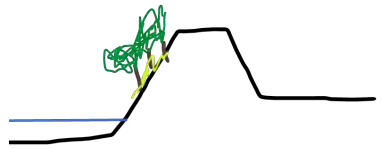
Wave wash erosion





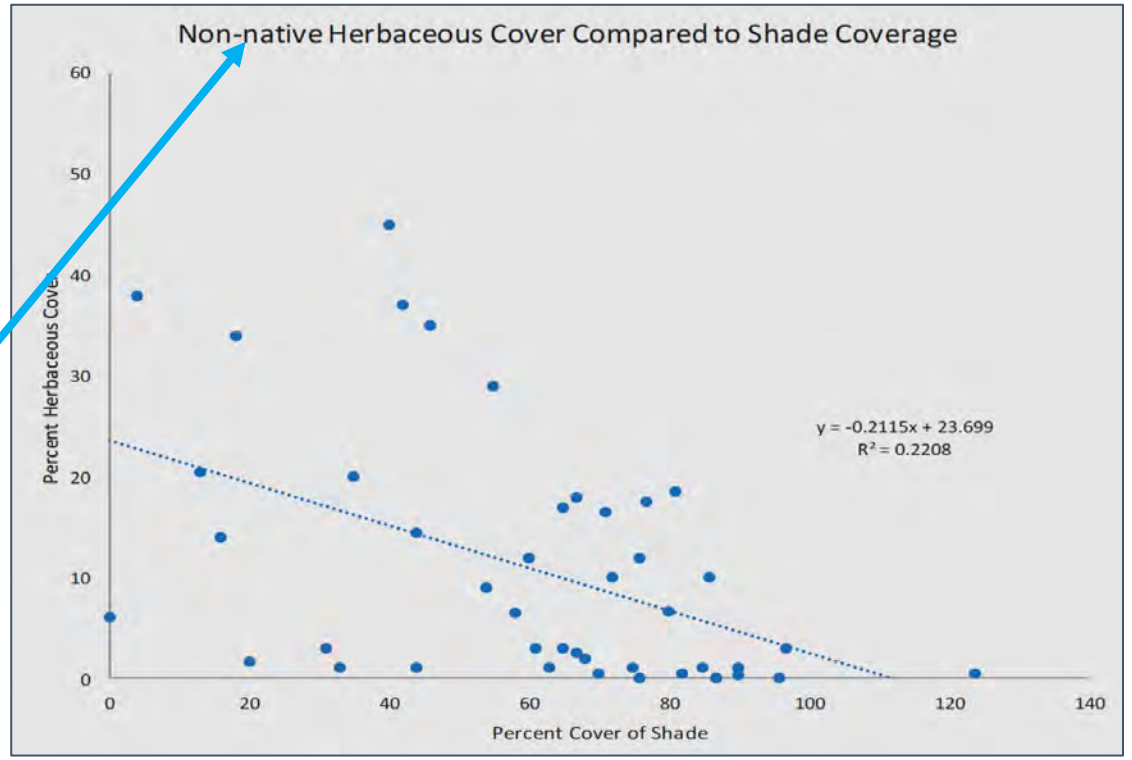
Ozeren et al. 2016

Sheet, rill and fluvial erosion



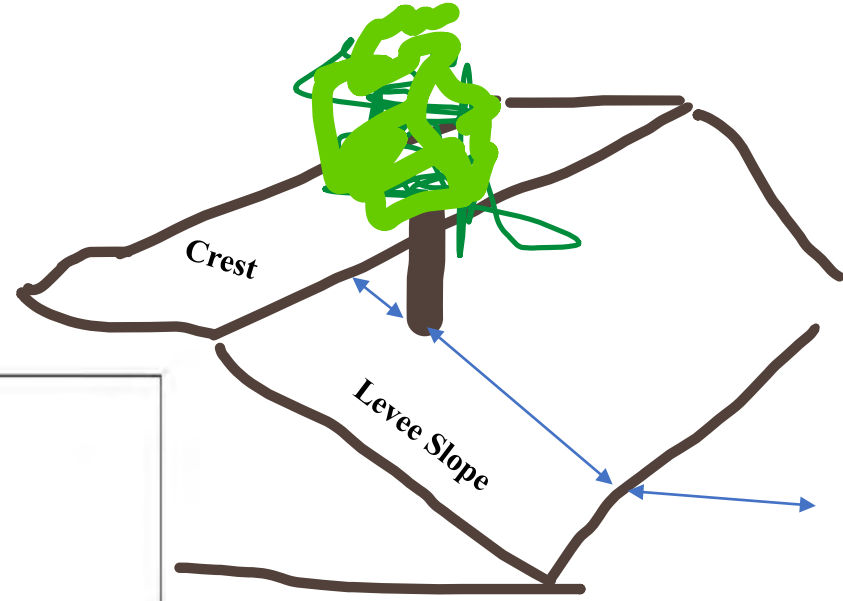
Vegetation cover on slopes (USACE 2019 and 2020)

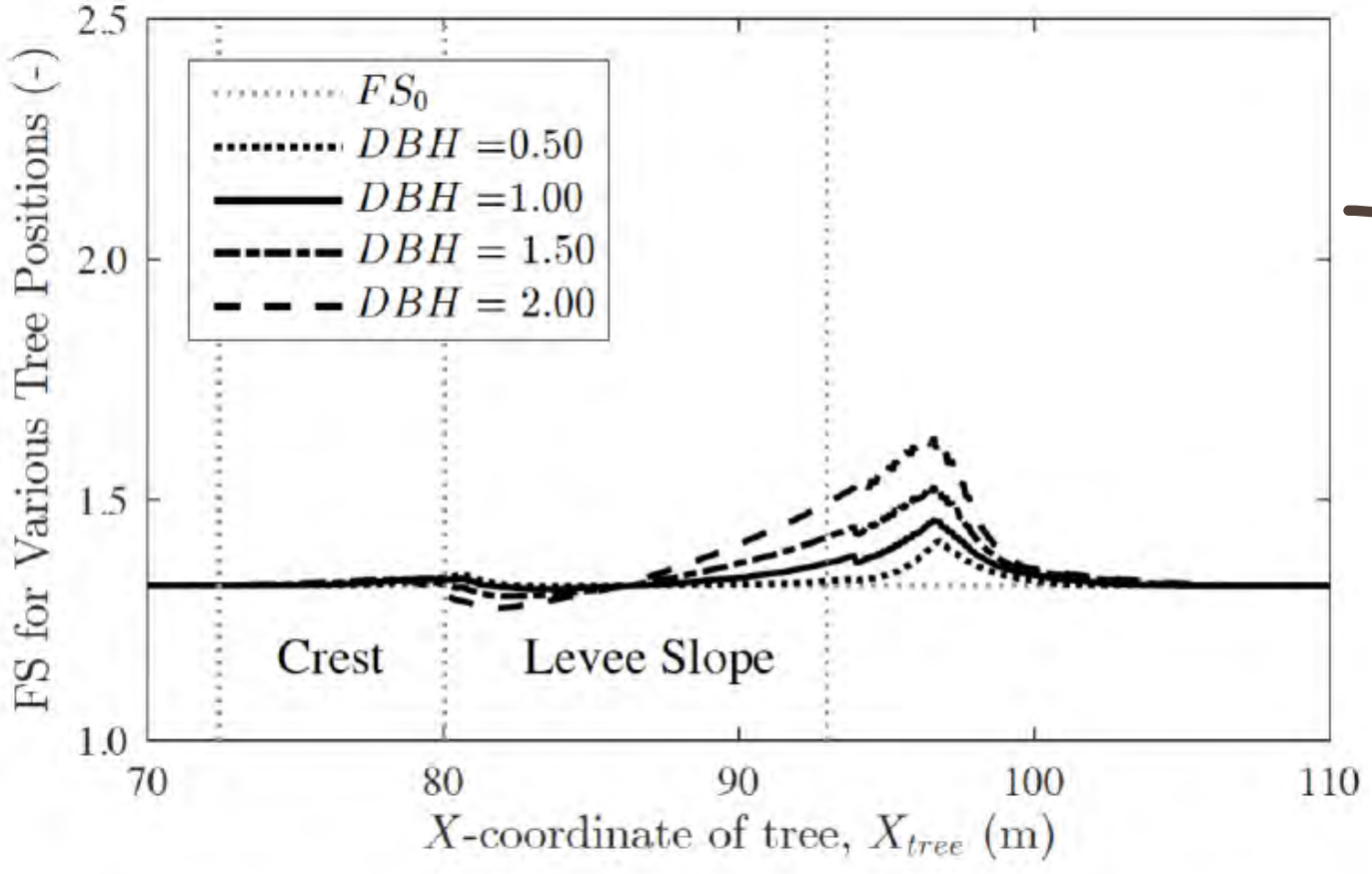
- "Habitat monitoring on the sites over the last 10 years has found that woody vegetation cover is positively correlated with native herbaceous cover and negatively correlated with non-native, invasive, herbaceous cover."
- Non-native herbaceous provides poor erosion control and presents fire hazard.
- The hot, dry climate of California does not allow for a year-round coverage of solely grasses without irrigation. Lacking irrigation or shade, the grasses will dry, die, and erosion is likely to occur.
- *Implications for adjacent and setback levees?*

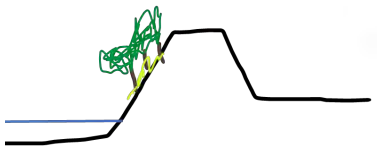


Guerrero et al. 2018

Geotechnical slope failure



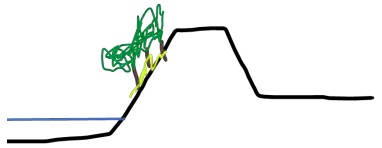




Habitats and water quality

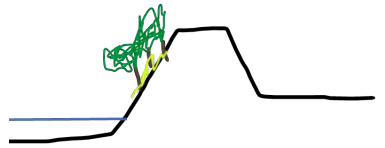
Effects of woody vegetation on floodplains and banks

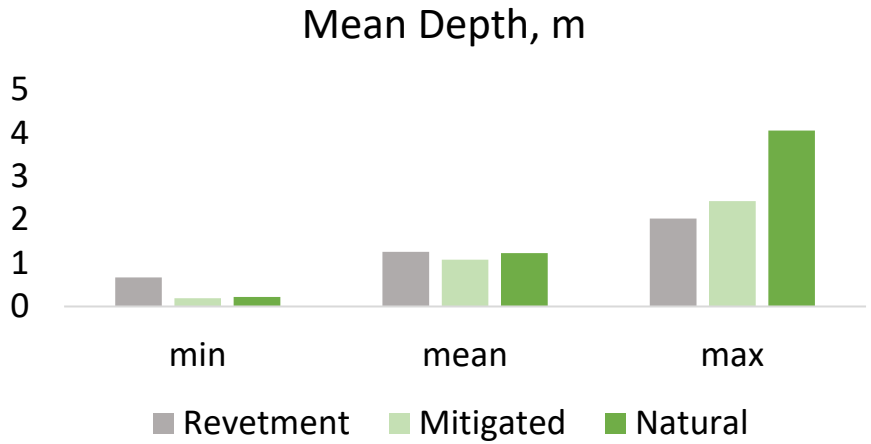
Levee vegetation and habitats

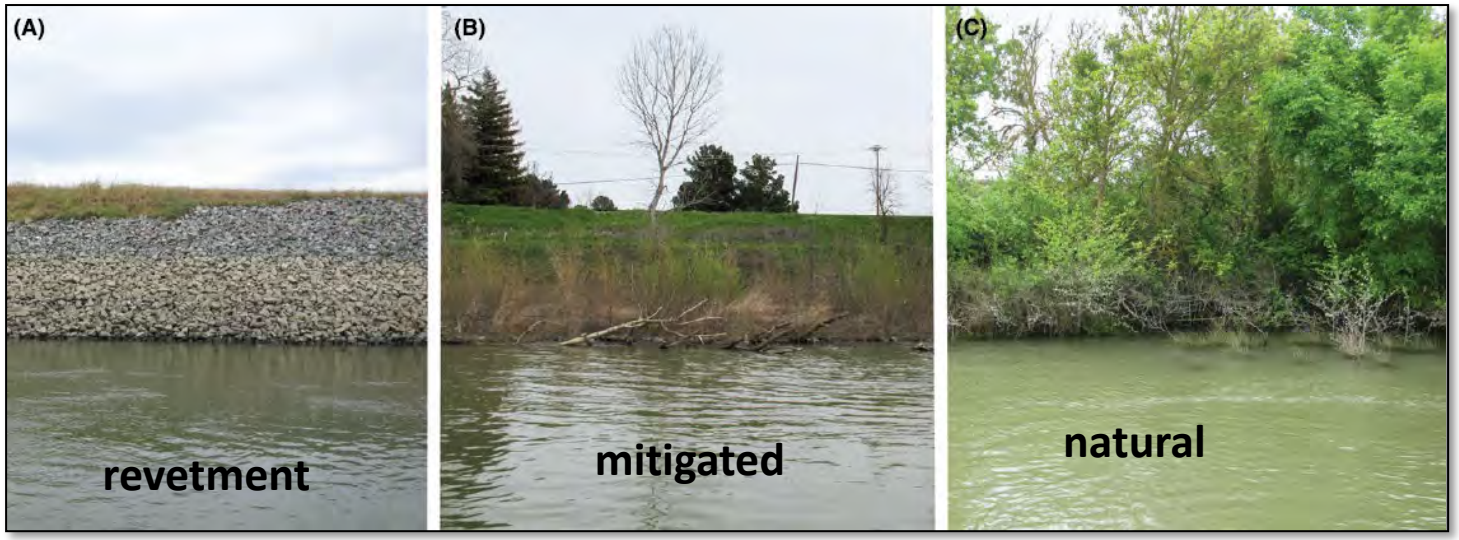


- Habitat for terrestrial riparian species
- Terrestrial insects to water
- CPOM (leaves, twigs, limbs) to water

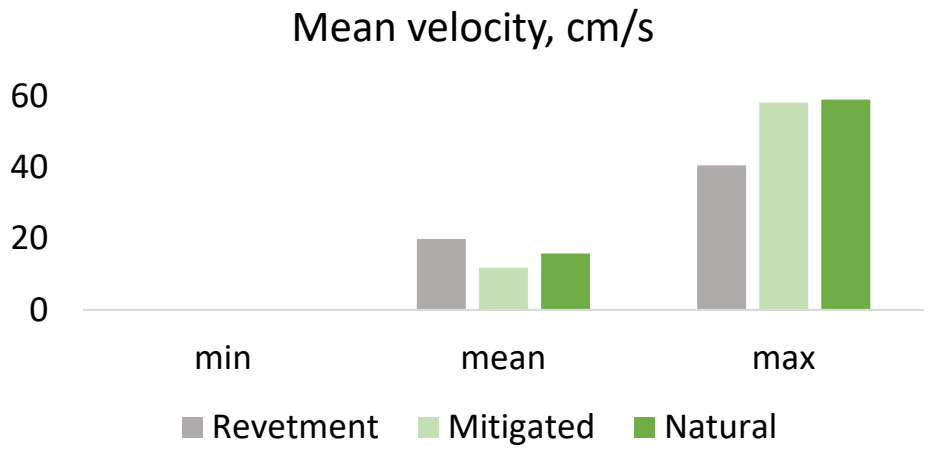
Levee vegetation and (fish) habitat

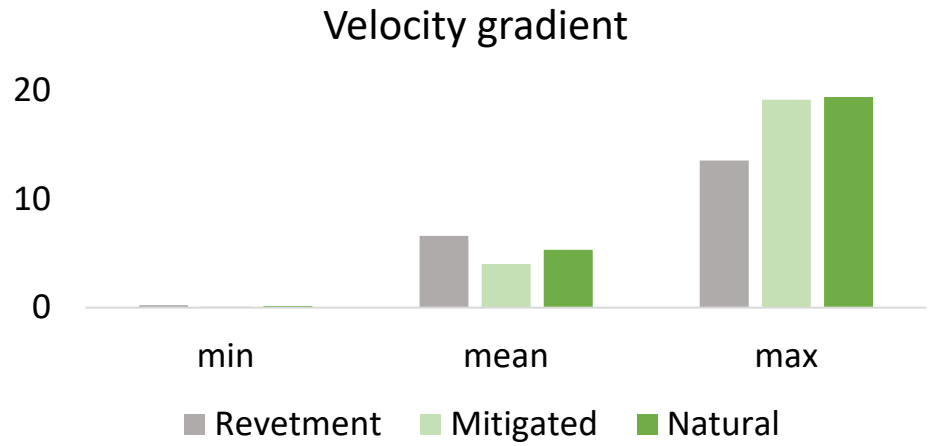




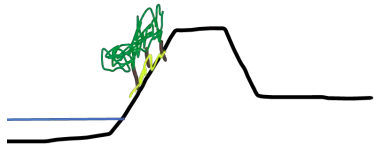


Hellmair et al. 2018

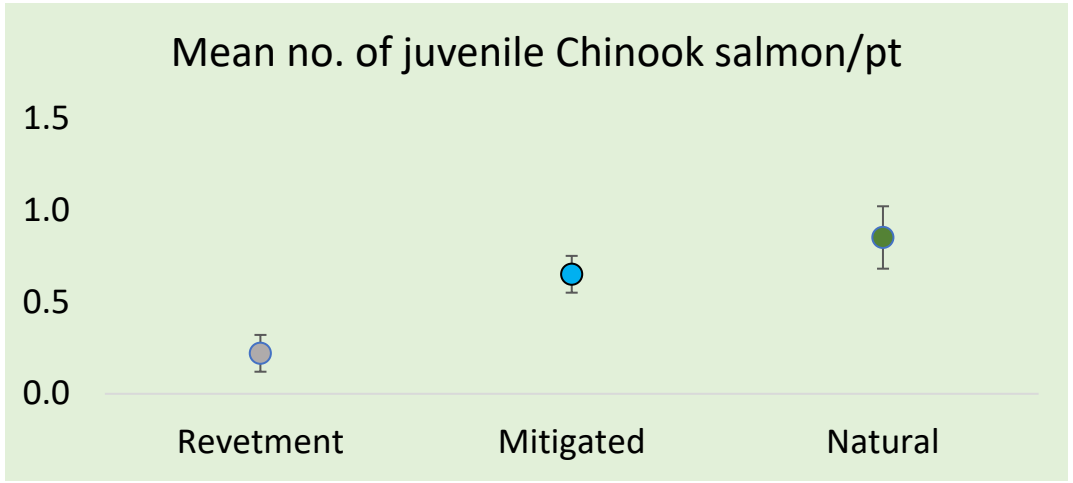


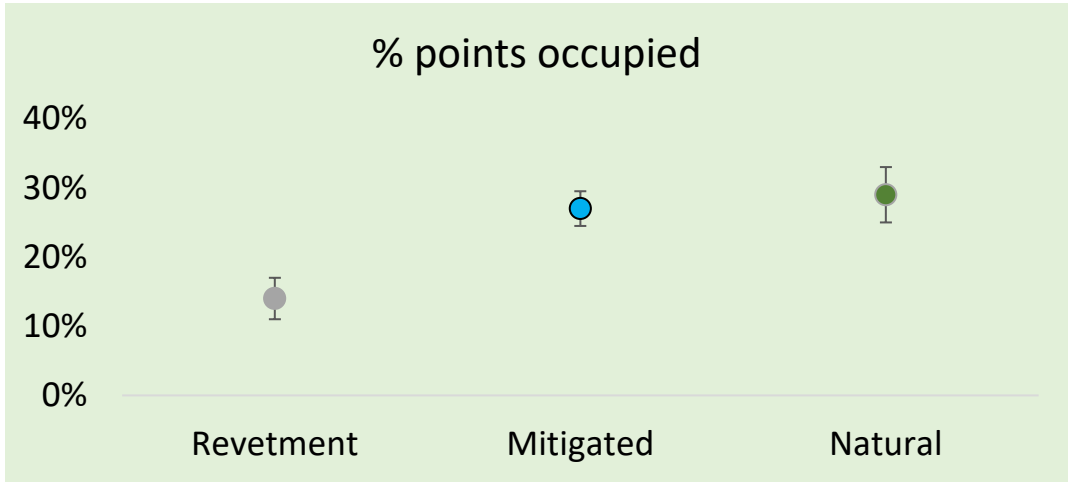


Levee vegetation and habitat

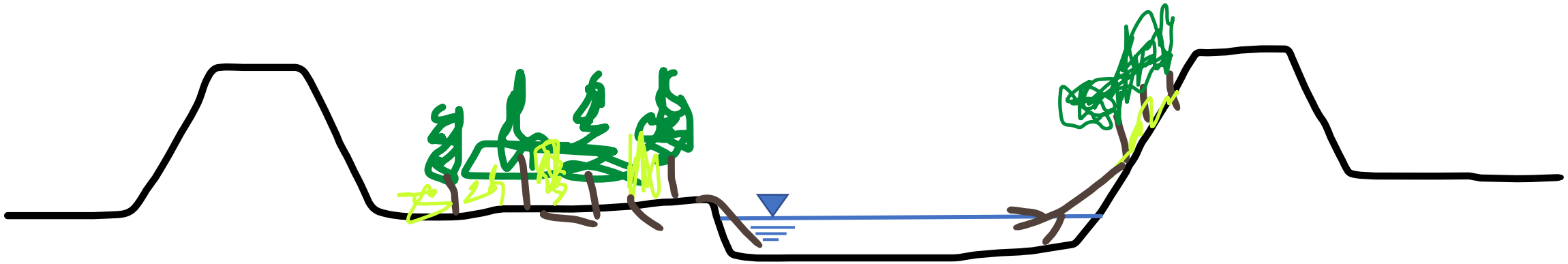


Hellmair et al. 2018





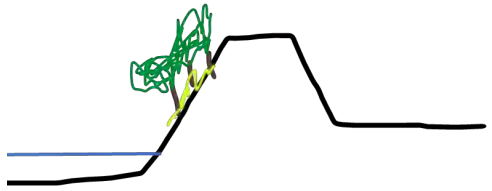
Levee vegetation as large wood source



Wood provides

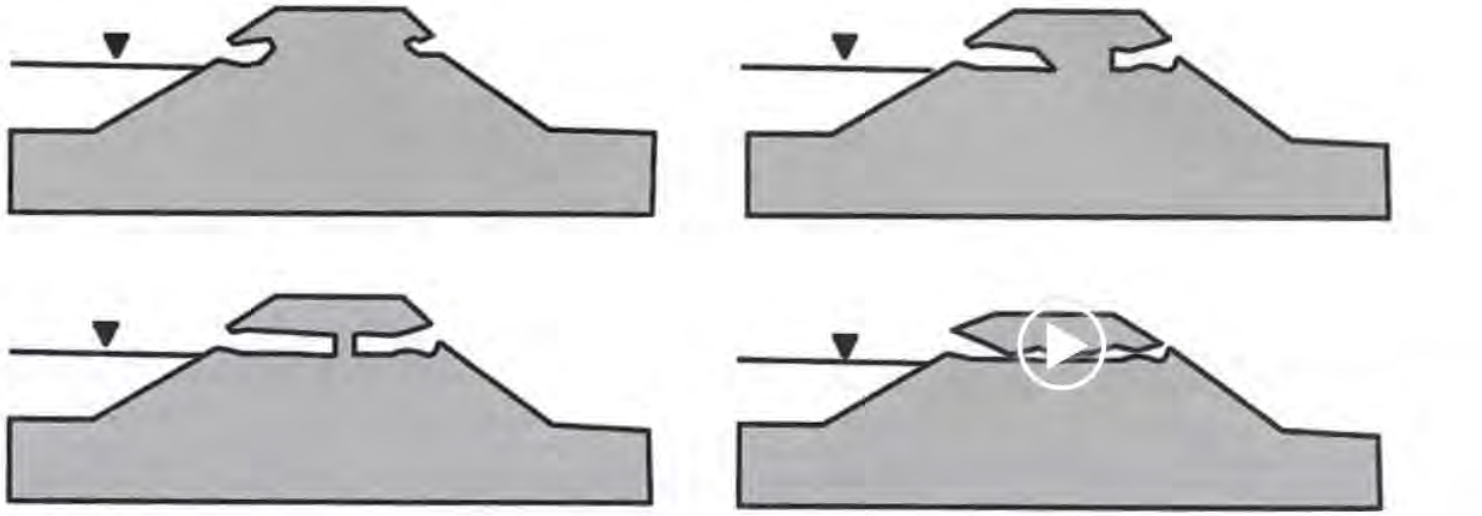
- Habitat for terrestrial species and amphibians
- Substrate for aquatic macroinvertebrates
- Food for macroinvertebrates in the form of biofilms and fungi
- Creates geomorphic and hydraulic complexity—velocity refugia and substrate diversity
- Hiding cover

Animal burrows



- Strong association between tree cover and burrow frequency
- Hazard to levees due to **trees** is largely anecdotal and conjectural
- Hazard due to **animal burrows** is well documented in US and internationally. Animal burrows have been cited as causal factors or probable factors in numerous levee failures (Dixon 1922, Fitzgerald and Thompson 1988, Paul and Slaven 2009, Harder et al. 2009, U.S. Bureau of Reclamation 2008, Bayoumi and Meguid 2011, Harder 2012c).

International Levee Handbook 2013



Sequence of Levee Failure due to Through-Embankment Burrowing

In 1993 and 1994, there were 13 Levee Breaches
in the Rhone River Delta Caused by Animal Burrows

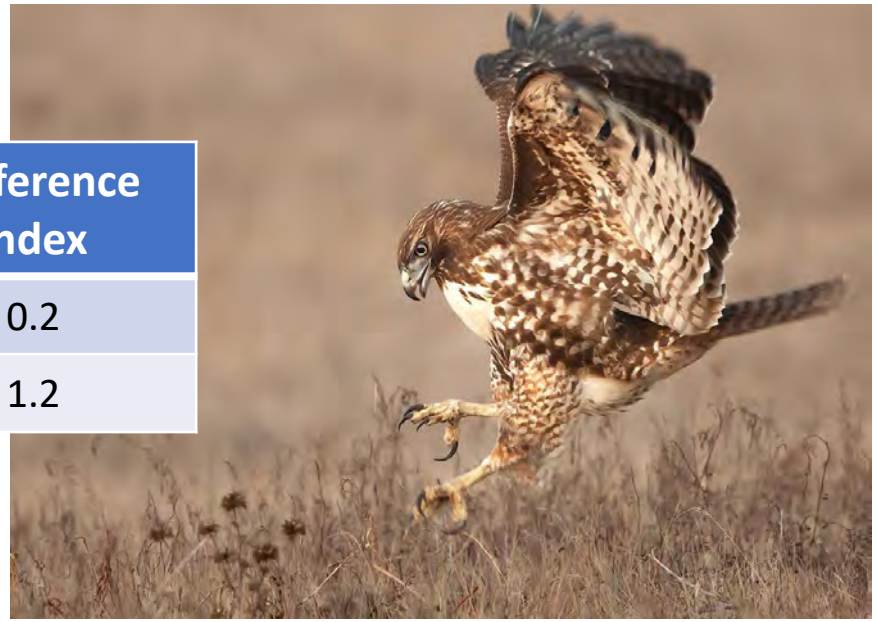
CIRIA 2013

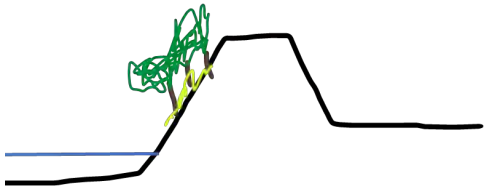
Trees provide habitat for raptors

Ground squirrels and levee vegetation

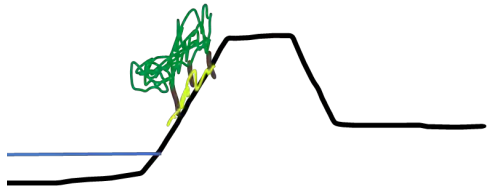
Canopy	Availability, %	Use, %	Preference index
Tree cover	22.3	4.3	0.2
Open	77.7	95.7	1.2

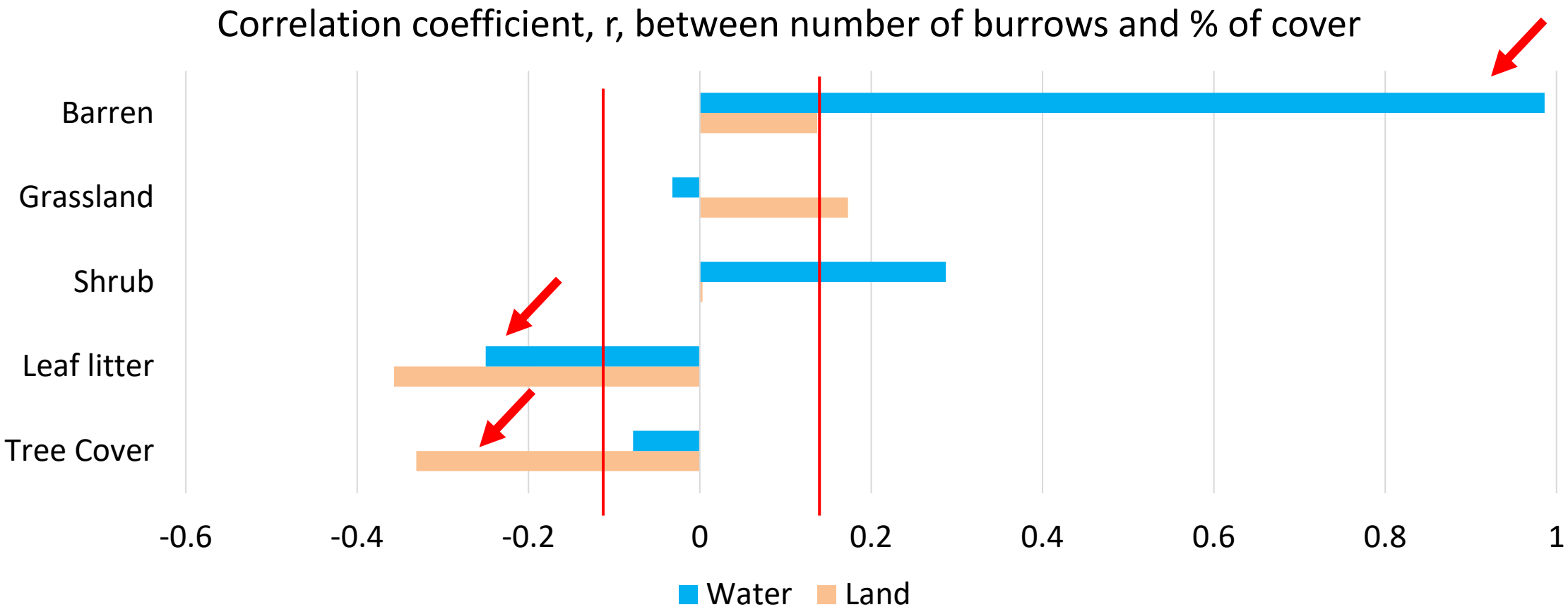
Use/Availability = Preference





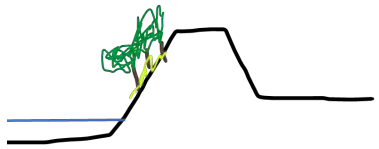
Vegetation and burrows





Ordenana et al. 2012

Levee vegetation and shade



Levee vegetation along Puyallup River, Puyallup, WA

Pierce County Public Works 2017

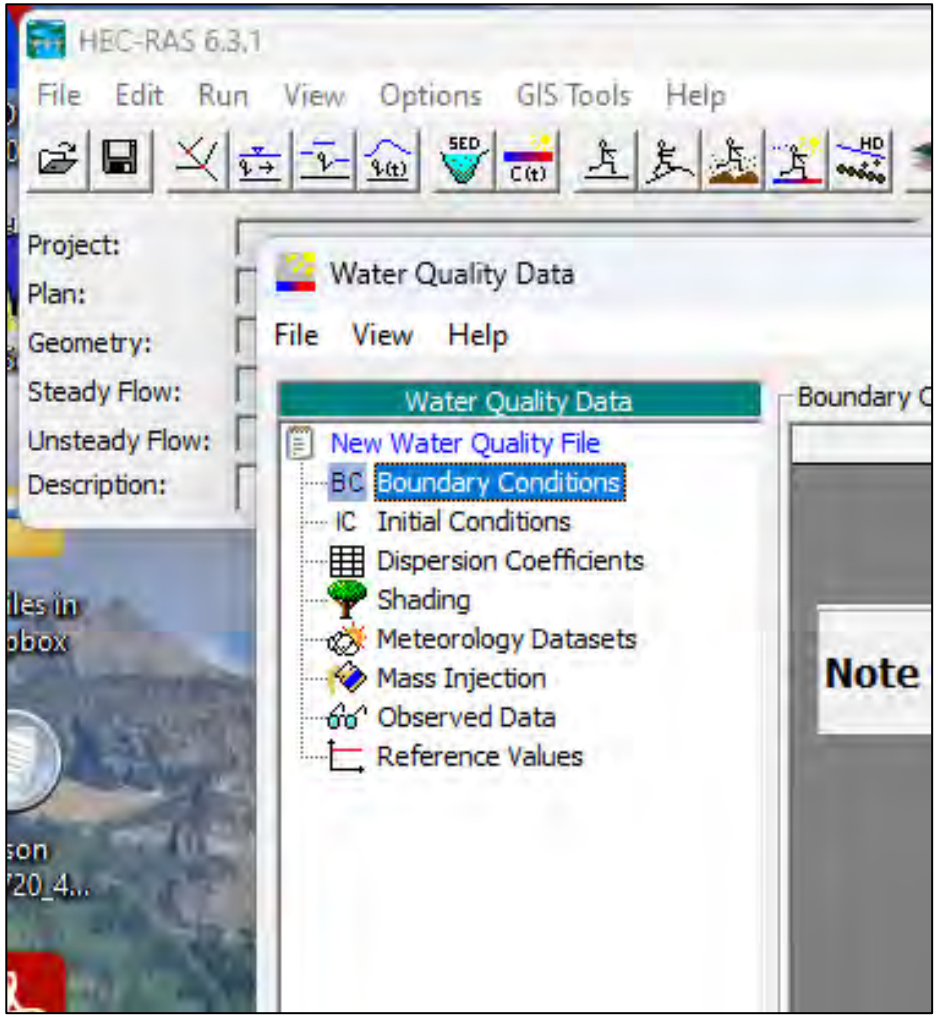
Meta-analysis effects of wooded riparian zone on small to medium sized stream temperatures

Degrees C cooler with woody bank veg

Season	Mean	Max
Summer	0.57	3.26
Spring	0.26	2.60
Overall	0.39	3.16

Bowler et al. 2012

Simulation of shade effects on stream temperature



Noa-Yarasca et al. 2023

Conclusions

Natural floodplains provide important services in terms of flood peak attenuation, storage of sediments, retention of pollutants and habitats. Floodplains may also provide aesthetic and recreational benefits.

Levees necessarily disconnect floodplains and main channels and therefore eliminate many of these services.

Woody vegetation on levee slopes and on waterside berms or floodplains mitigate some of the adverse impacts of levees, especially those on aquatic ecosystems and water quality.

Setback levee designs are an attractive option, but feasibility is limited.

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