USDA Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE

Effects of riparian vegetation on bank erosion

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Goodwin Creek Bendway, MS, January 2023

Examples of observed vegetation effects on streambank erosion

- Reduced erosion/width:
  - Smith (1976): **20,000 times more resistance** to erosion of vegetated soils
  - Beeson and Doyle (1995): erosion **30 times more prevalent** on non-vegetated bends
  - Burckhardt and Todd (1998): unforested migration rate **3x larger**
- Increased erosion/width:
  - Davies-Colley (1997): increasing width from pasture to native to forested riparian zones.
  - Trimble (1997): grassed reaches narrower than forested reaches

Vegetation effects on streambank erosion

- Resistance to surface erosion
- Resistance to failure
- Above ground biomass (stems and leaves)
- Below ground biomass (roots)
- Vegetation affects erosion through:
  - Raindrop interception
  - Increased infiltration and infiltration capacity
  - Soil water transpiration
  - Increased surface roughness
  - Soil aggregate stability
  - Soil reinforcement

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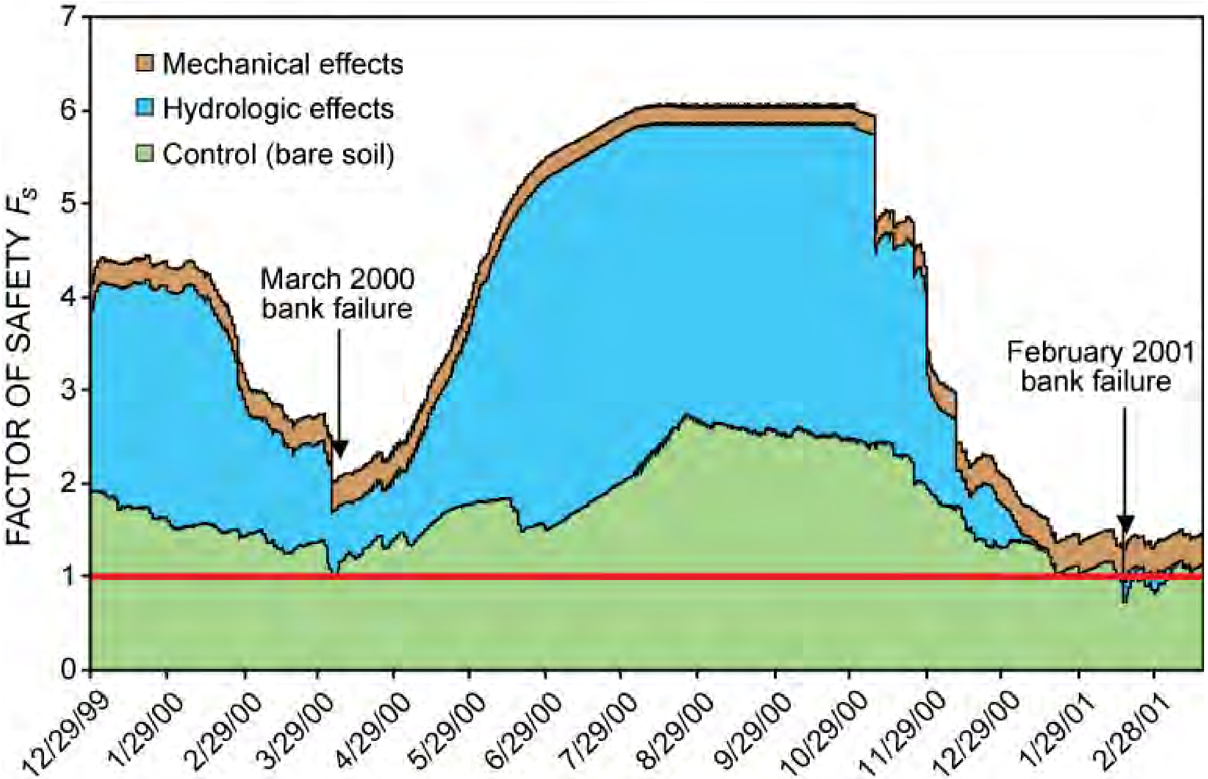
Effects of vegetation on streambank stability

	Mechanical	Hydrologic
Stabilizing	Increased strength due to roots	Transpiration and canopy interception
Destabilizing	Surcharge	Increased infiltration rate and capacity

Hydrological versus mechanical effects



From Simon and Collison, ESPL, 2002

Mechanical findings

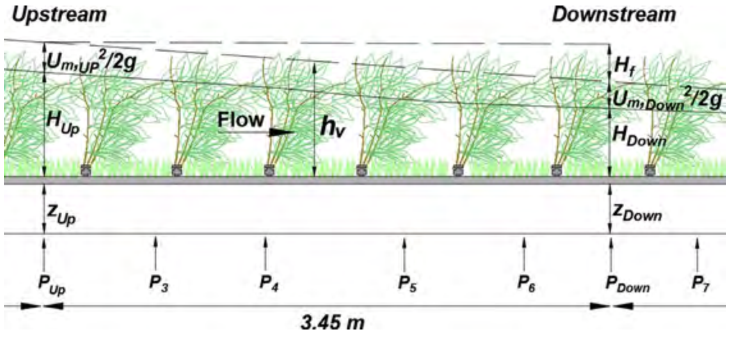
- Trees add 5-20 kPa cohesion to soil, over about 0-100 cm depth (black willow least effective)
- Clump grasses add 10-40 kPa cohesion
- Lots of small roots potentially provide greater strength than a few big roots
- However – most of the strength from trees actually comes from large sized roots – small roots make up too little area
- Significant strength achieved over 5-10 years growth

Hydrology findings

- 2% of rain is intercepted by riparian strip canopy (high intensity events, low canopy cover during winter/spring)
- Trees increase infiltration capacity, concentrating more water in upper 30-100 cm soil than on bare or grass-covered banks
- Trees maintain suction at depth (200-300 cm) into spring
- High matric suction at depth indicates deeper roots than found in survey (?)

Effects of vegetation on fluvial streambank erosion

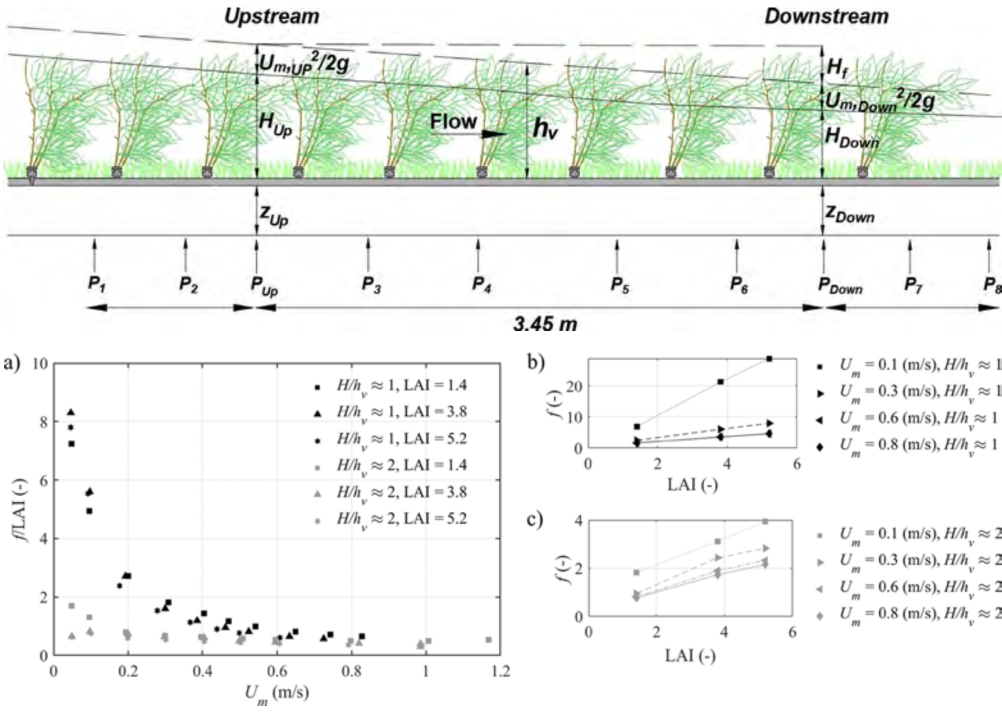
- Hydraulic: modification of exerted forces on the soil surface



- Soil mechanical: modification of erosion resistance

Hydraulic effects of vegetation on fluvial streambank erosion

- Bulk effect is an increased hydraulic resistance, generally reducing the spatially average flow magnitude
  - Complex interactions between tree/plant structure and flow magnitude
- Locally, it may lead to increased forces
  - Lateral and vertical mean flow acceleration
  - Increased turbulence



Box et al. (2021)

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Lower American River, CA

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Gumara River, Ethiopia

Hydraulic effects of vegetation on fluvial streambank erosion

Note, vegetation may also lead to bulk **sediment deposition**

Sacramento River, CA

Mechanical effects of vegetation on streambank erosion-resistance

- Improved soil structure (binding and cementing)

- Soil-root bonding

Tap root system†	Correction coefficient			Fibrous root system‡	Correction coefficient		
	Total roots	Root binding	Root bonding		Total roots	Root binding	Root bonding
HH	0.6067	0.9403	0.6453	ZSH	0.2979	0.6191	0.4812
HQ	0.6475	0.8840	0.7325	CMC	0.1799	0.8286	0.2171
AH	0.6848	0.9876	0.6934	BC	0.3040	0.8448	0.3598
TGH	0.3521	0.5695	0.6183	YZC	0.3176	0.8615	0.3687
HZZ	0.4883	0.8918	0.5476	BYC	0.4996	0.5580	0.8954

† AH, *Artemisia argyi* Levl. Et Vant.; HH, *Artemisia capillaris* Thunb.; HQ, *Astragalus melilotoides* Pall.; HZZ, *Lespedeza davurica* (Laxm.) Schindl; TGH, *Artemisia vestita* Wall. ex Bess.

‡ BC, *Leymus secalinus* (Georgi) Tzvel; BYC, *Bothriochloa ischcemum* (Linn.) Keng; CMC, *Stipa bungeana* Trin.; YZC, *Cleistogenes squarrosa* (Trin.) Keng; ZSH, *Poa sphondylodes* Trin.

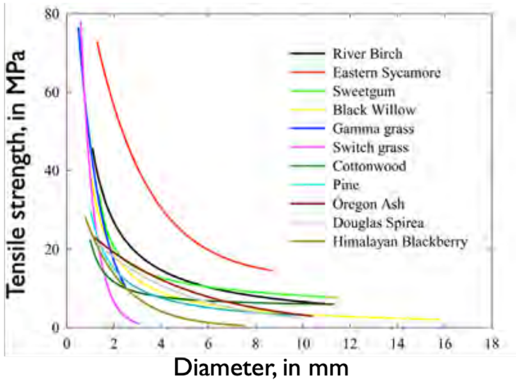
Wang & Zhang (2017)

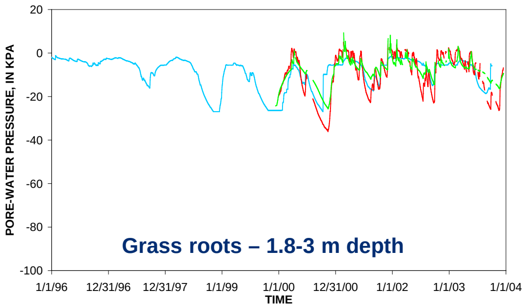
Assessment – Geotechnical stability

- Added cohesion by roots
  - Fiber bundle models such as RipRoot can quantify added cohesion
  - Extensive species database
- Added weight by trees
  - Offset by root mass reducing bulk soil weight
- Soil water movement feedback on pore-water pressure

$$\tau = c' + \sigma_n \tan\phi' - p\tan\phi^b$$

cohesion — pore-water pressure





Assessment – Fluvial erosion

- Applied force
  - Controlled by the imposed roughness
  - Partitioning of roughness: surface roughness, drag, and cover

$$\tau = \gamma RS(1 - C_v)\frac{n'}{n_t}$$

- Resisting force
  - Generally, two or three parameters: critical shear stress and erodibility coefficient
  - Can be measured in the field or lab by a range of instrumentation

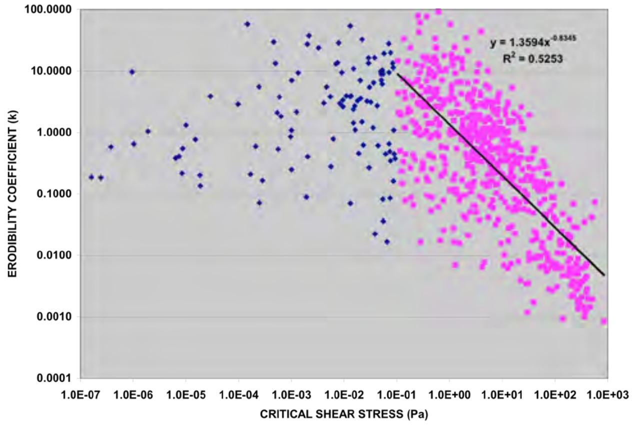
Erosion resistance parameters

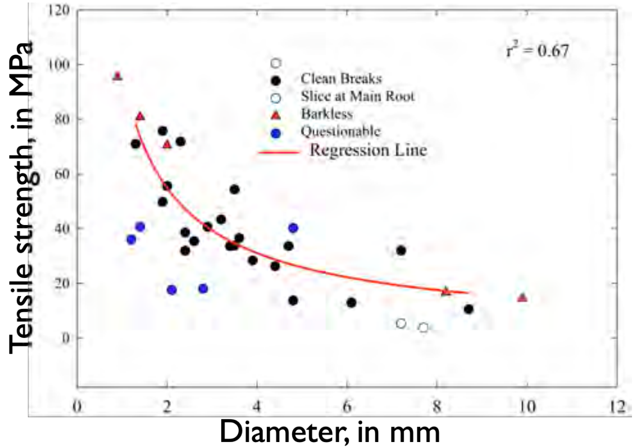
$$E = K\left(\tau - \tau_c\right)$$

applied force

Assessment – Accounting for variability

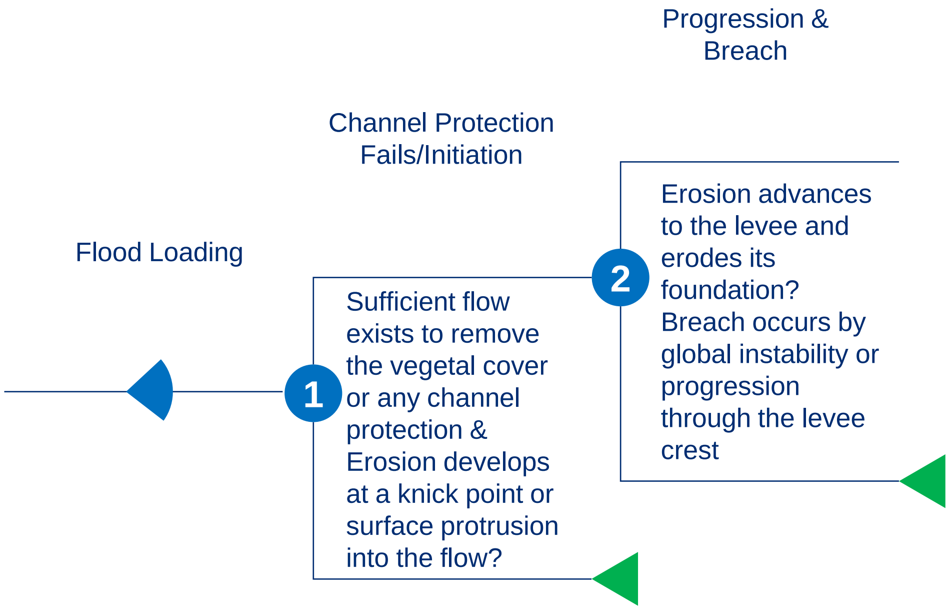
- Soil erosion-resistance properties vary significantly both in space and time
- Vegetation properties vary significantly in space and time
- Best addressed using a probabilistic approach
- USACE-SPK developed a methodology for levees around the City of Sacramento





Application by USACE Sacramento District to Lower American River

- Extensive calibration of deterministic and stochastic BSTEM models
- Development of a riverine erosion event tree



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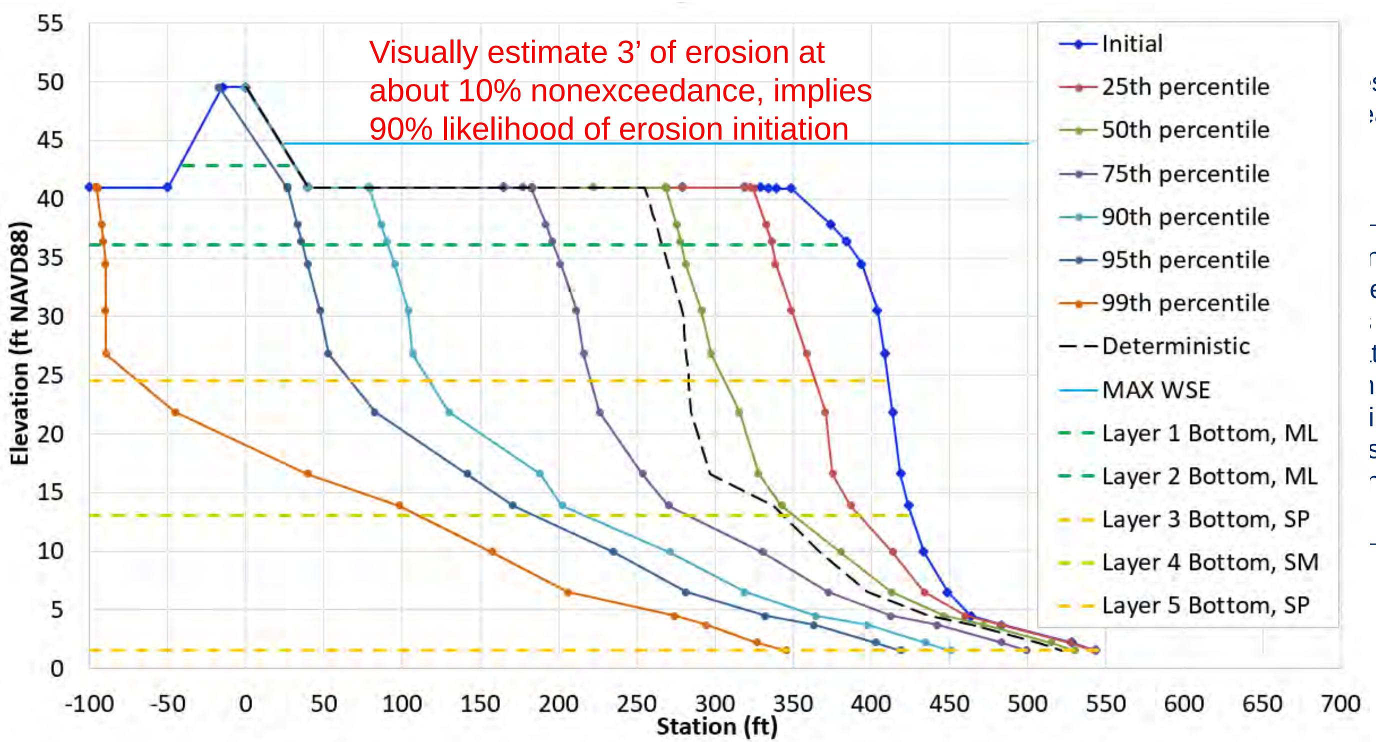

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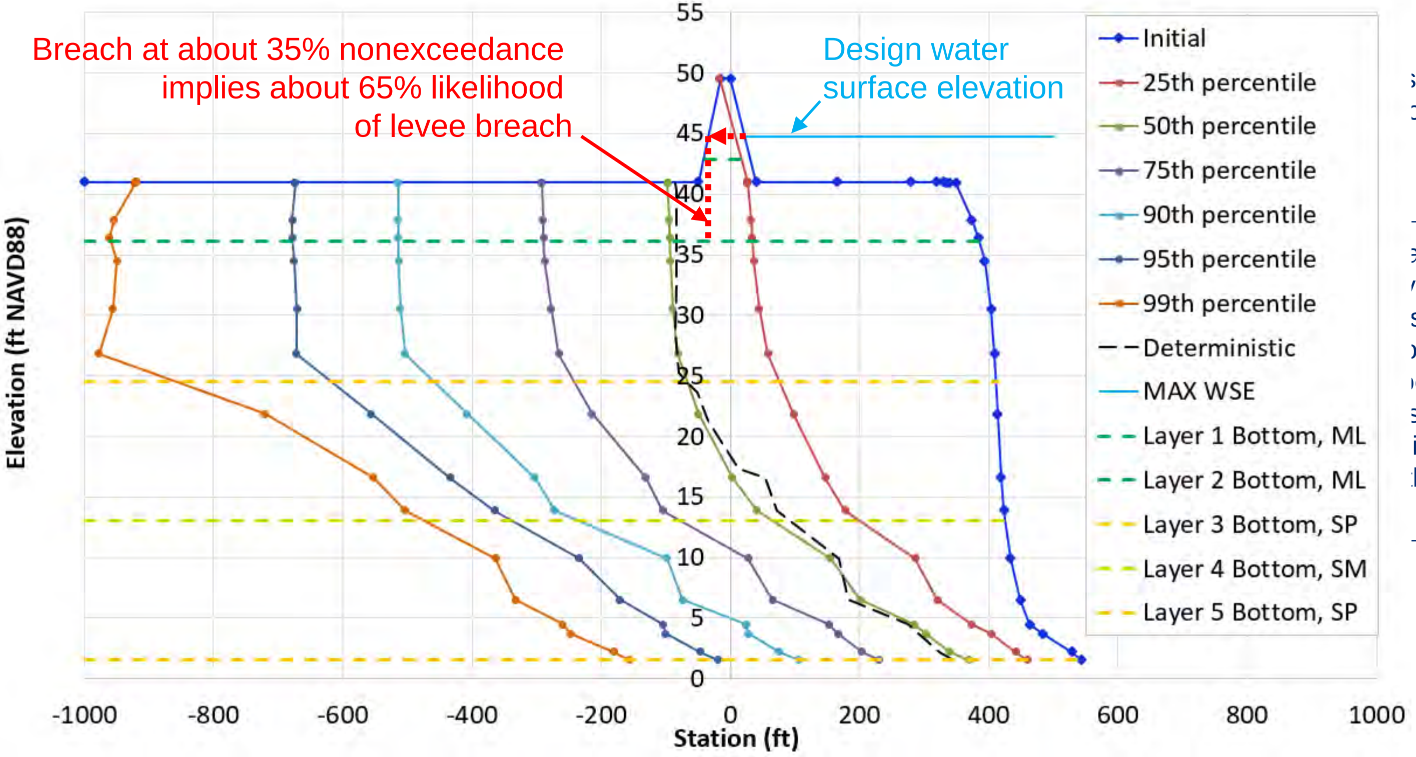

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