San Joaquin River Restoration Program

Predicting Increased Channel Stability due to Vegetation Using Two-Dimensional Hydraulic Modeling and RipRoot

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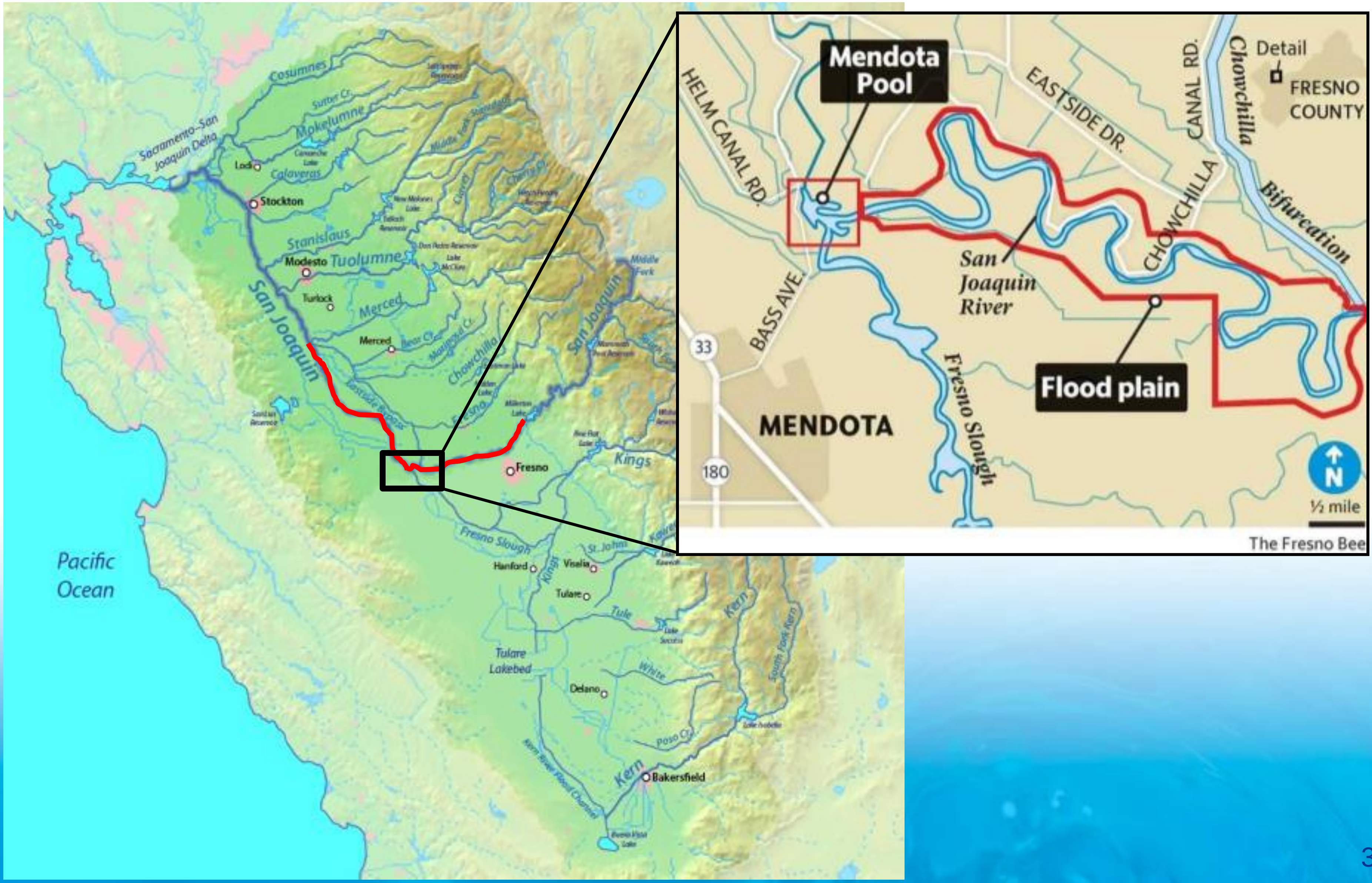
SJRRP Background

The SJRRP is a collaborative, multi-agency effort to restore **fish** and **flows** to the San Joaquin River, while **minimizing adverse impacts** to water users.

SJRRP Project Area



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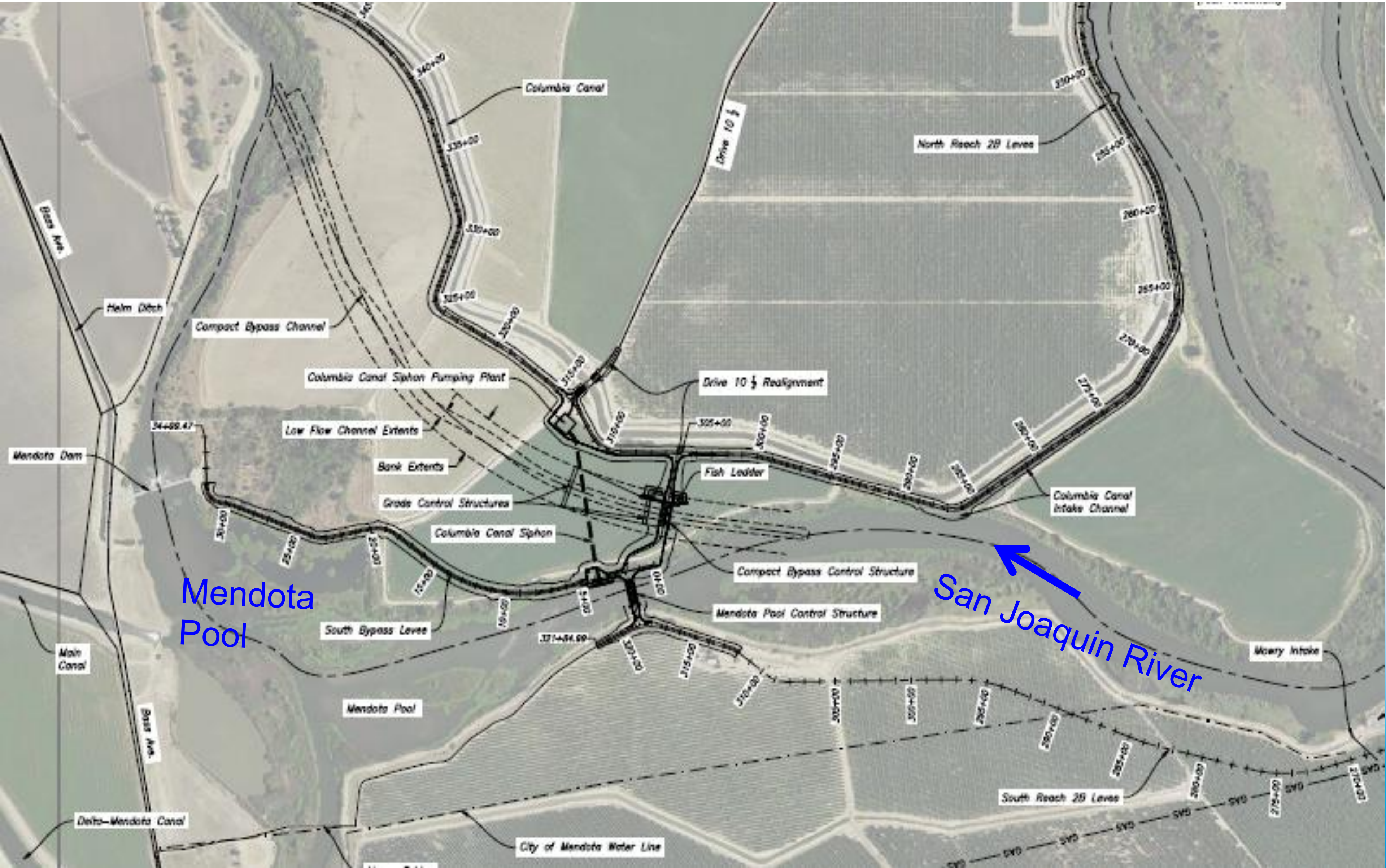
Passage: The Mendota Pool Bypass Project



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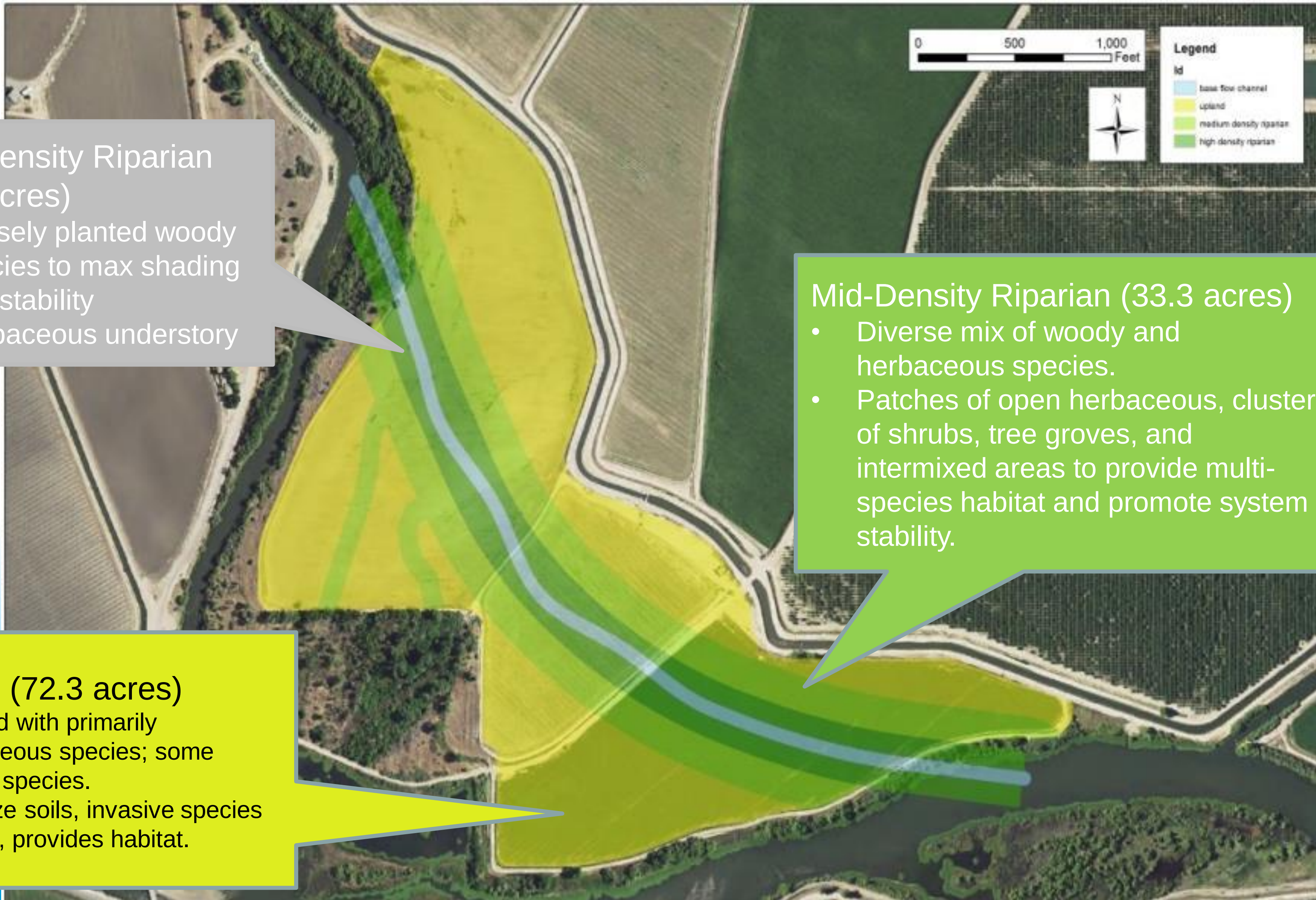
Bypass Revegetation Plan



High-Density Riparian (21.9 acres)

- Densely planted woody species to max shading and stability
- Herbaceous understory

Mid-Density Riparian (33.3 acres)

- Diverse mix of woody and herbaceous species.
- Patches of open herbaceous, cluster of shrubs, tree groves, and intermixed areas to provide multi-species habitat and promote system stability.

Upland (72.3 acres)

- Seeded with primarily herbaceous species; some woody species.
- Stabilize soils, invasive species control, provides habitat.

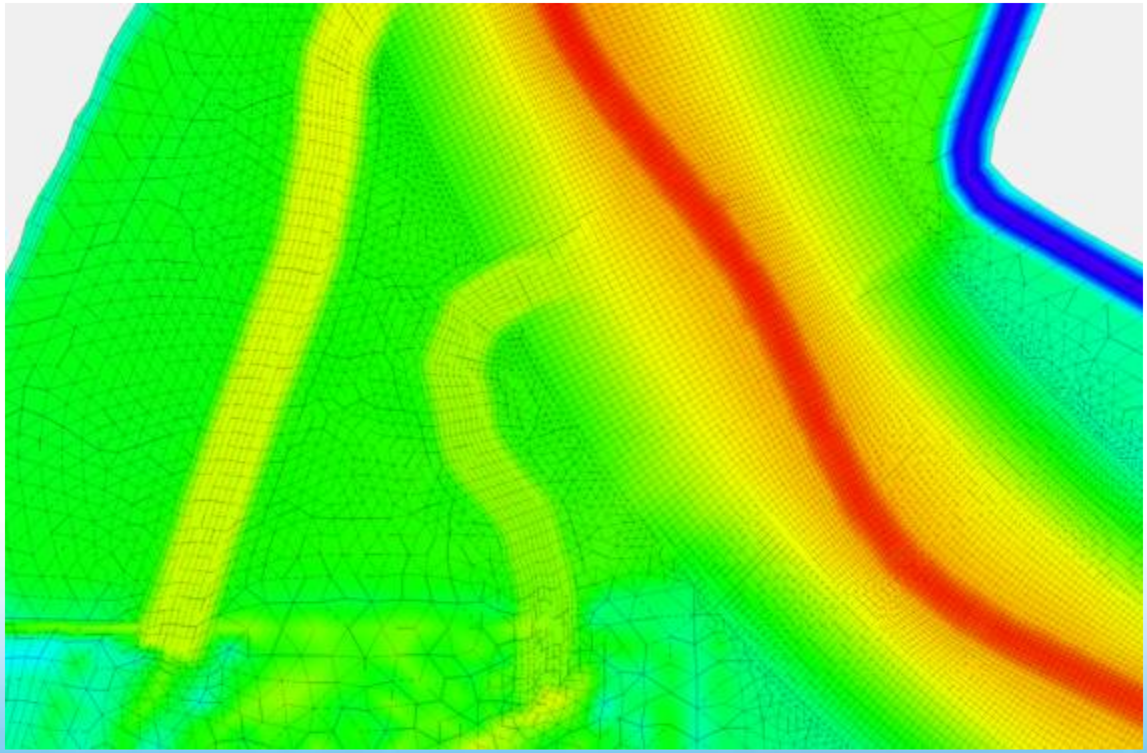
Objectives

- Is vegetation sufficient to resist **erosion** and **undercutting** in the compact bypass, or is additional bank protection needed?
  - Calculate shear stresses within the bypass channel
  - Determine time required for vegetation establishment to minimize erosion and potential bank failure

Hydraulic Model: SRH-2D (Lai, 2009)

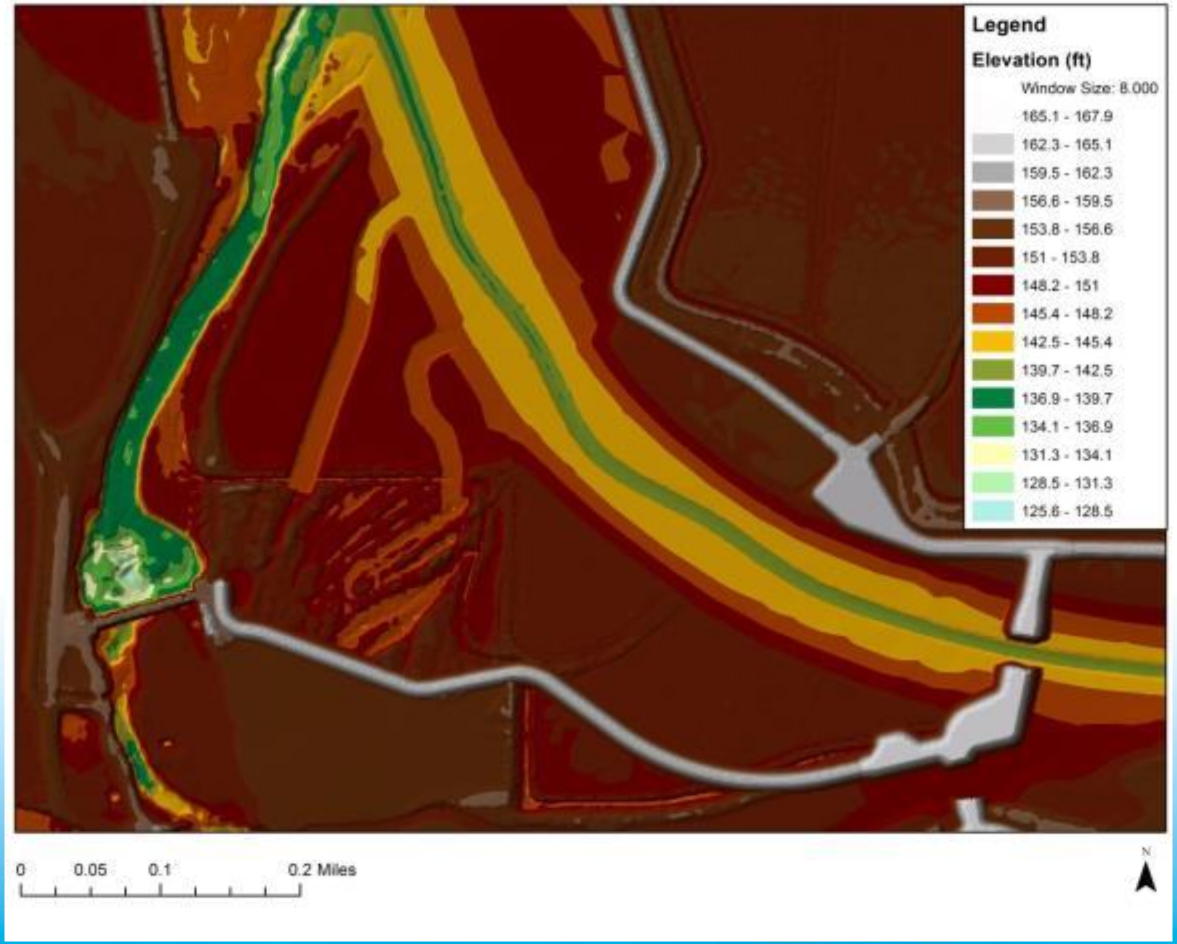
- Solves the depth-averaged Navier-Stokes equations
- Produces two-dimensional (x,y) mean flow field and water depth
- Bed shear stresses calculated via Manning’s Resistance equation

SRH-2D: Mesh



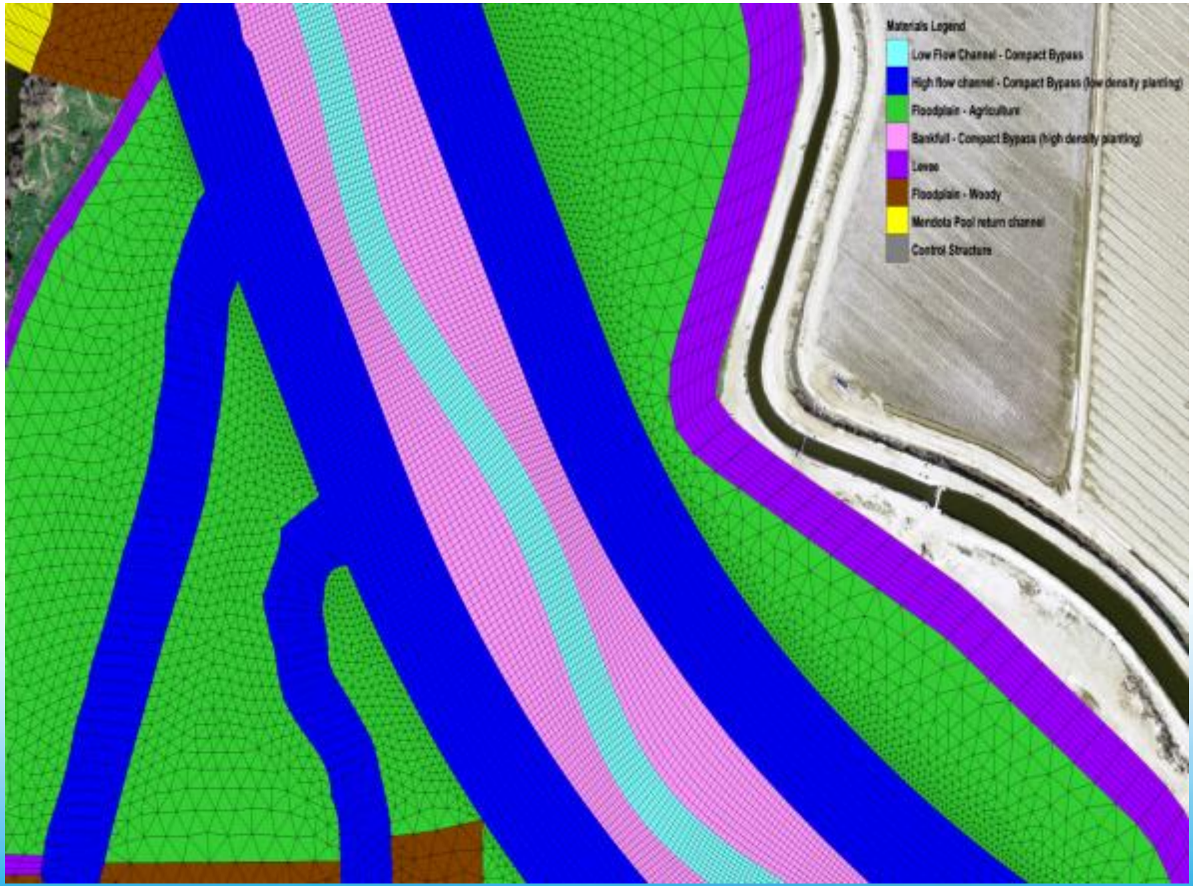
- Rectangular cells in channel, triangular in floodplain
- In channel, cells ranged from 7 to 20 feet laterally, and 10 to 30 feet longitudinally

SRH-2D: Terrain



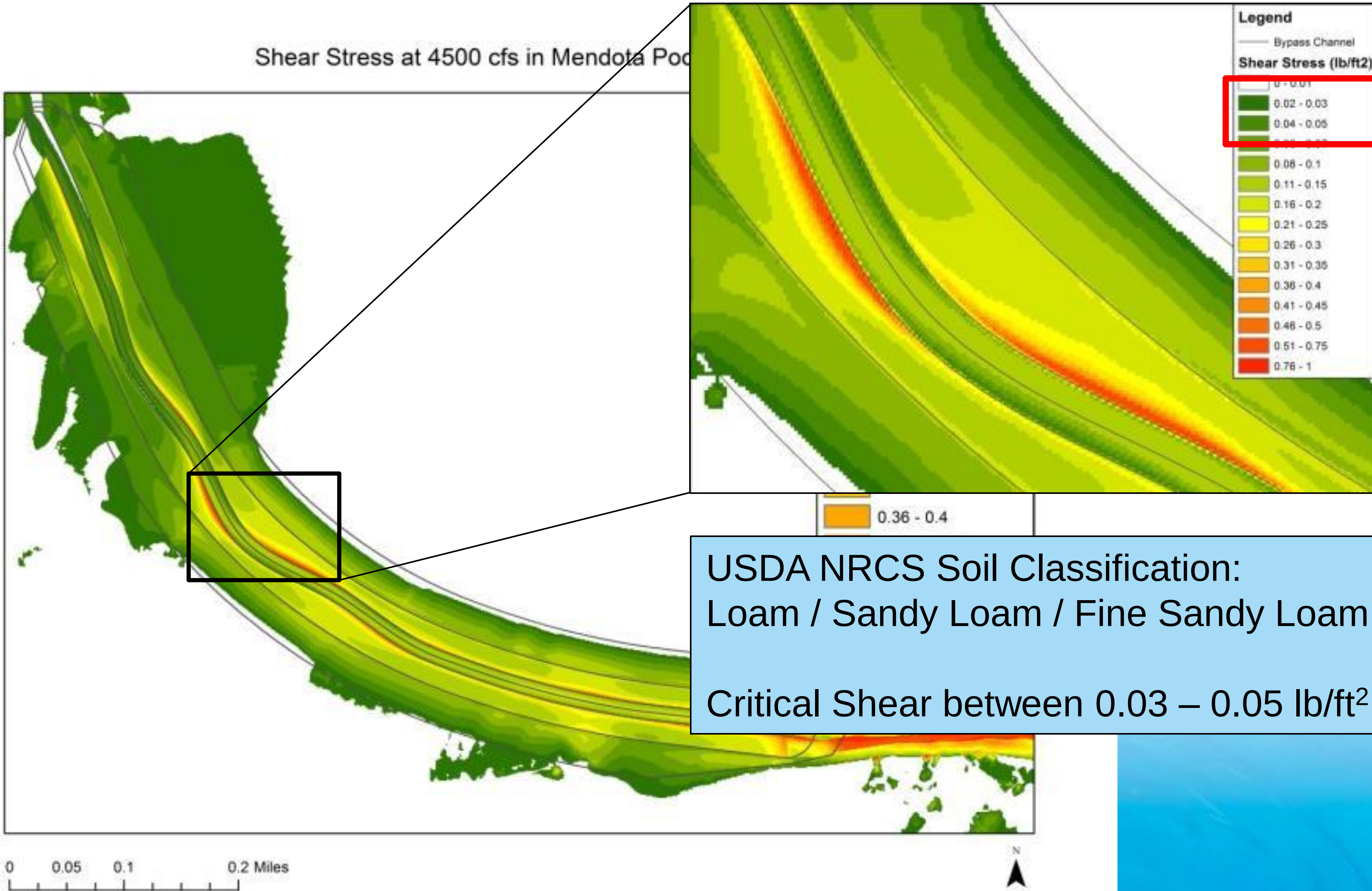
- Elevations from 2008 LiDAR and design geometry of channel
- Upstream incision and downstream aggradation approximated to remove abrupt transitions

SRH-2D: Roughness



- Manning's n values for bypass averaged between upstream and downstream reaches
- Represents future conditions

Results: Shear Stress



USDA NRCS Soil Classification:
Loam / Sandy Loam / Fine Sandy Loam

Critical Shear between 0.03 – 0.05 lb/ft^2

Vegetation Effects

- Above ground biomass can reduce shear stress applied to bottom sediment
  - Drag (reduce near bed velocities)
  - Shielding (flexible vegetation)
- Roots increase the apparent cohesion of soil
  - Mechanically (shear resistance)
  - Hydrologically (reducing pore water pressure)

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Shear Resistance: NRCS

- Retardance curve index (C_I): Potential of vegetation to develop flow resistance
- Cover Index (C_F): Physical cover for erosion prevention

Table 8–8 Characteristics of selected grass species use in channels and waterways

Grass species	Height at maturity (ft)	Height at maturity (m)
Cool-season grasses		
Creeping foxtail	3–4	0.9–1.2
Crested wheatgrass	2–3	0.6–0.9
Green needlegrass	3–4	0.9–1.2
Russian wild rye	3–4	0.9–1.2
Smooth bromegrass	3–4	0.9–1.2
Tall fescue	3–4	0.9–1.2
Tall wheatgrass		1.2–1.5
Western wheatgrass	2–3	0.6–0.9
Warm-season grasses		
Bermudagrass	3/4–2	0.2–0.6
Big bluestem	4–6	1.2–1.8
Blue grama	1–2	0.3–0.6
Buffalograss	1/3–1	0.1–0.3
Green spangletop	3–4	0.9–1.2
Indiangrass	5–6	1.5–1.8
Klein grass	3–4	0.9–1.2
Little bluestem	3–4	0.9–1.2
Plains bristlegrass	1–2	0.3–0.6
Sand bluestem	5–6	1.5–1.8
Sideoats grama	2–3	0.6–0.9
Switchgrass	4–5	1.2–1.5
Vine mesquitegrass	1–2	0.3–0.6
Weeping lovegrass	3–4	0.9–1.2

$$C_I = 2.5\left(h\sqrt{M}\right)^{\frac{1}{3}} \qquad \text{(eq. 8–28)}$$

where:

h = the representative stem length

M = the stem density in stems per unit area

$$T_{va} = C_F * C_I$$

Table 8–10 Properties of grass channel linings values (apply to good uniform stands of each cover)

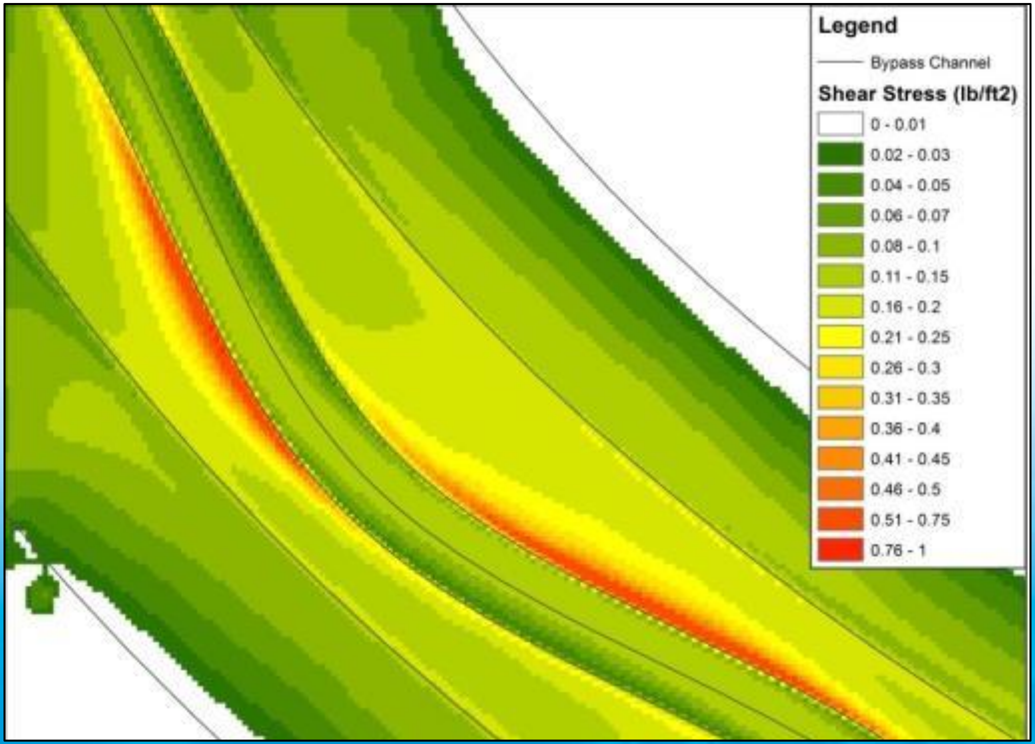
Cover factor (C_F)	Covers tested	Reference stem density (stems/ft²)	Reference stem density (stems/m²)
0.90	Bermudagrass	500	5,380
	Centipede grass	500	5,380
0.87	Buffalograss	400	4,300
	Kentucky bluegrass	350	3,770
	Blue grama	350	3,770
0.75	Grass mixture	200	2,150
0.50	Weeping lovegrass	350	3,770
	Yellow bluestem	250	2,690
0.50	Alfalfa	500	5,380
	Lespedeza sericea	300	3,280
0.50	Common lespedeza	150	1,610
	Sudangrass	50	538

Multiply the stem densities given by 1/3, 2/3, 1, 4/3, and 5/3 for poor, fair, good, very good, and excellent covers, respectively. Reduce the C_F by 20% for fair stands and 50% for poor stands.

USDA NRCS National Engineering Handbook: Steam Restoration Guidelines, 2007

Allowable Shear Stress

Stem Length (h) (ft)	Stem Density (M) (stems/ft^2)	Allowable Stress (T_{va}) (lb/ft^2)
0.5	50	2.86
2	200	5.71
4	200	7.19



Caveats

- Localized high shear, at scales finer than the 2D model grid, could cause scour/erosion that is not represented in the 2-D hydraulic model

- Weak points are critical; can cause rapid erosion

- Grasses are susceptible to failure by undercutting

Root Reinforcement Model: RipRoot (Pollen and Simon, 2005)

- RipRoot is a component of the Bank Stability and Toe Erosion Model (BSTEM) a spreadsheet model to determine stable bank conditions
- RipRoot application for root strength can be run separately from BSTEM
- Inputs
  - Soil characteristics
  - Bank protection
  - Species composition and age

    OR

  - Count of roots at different size classes

RipRoot: Root Strength

- Simulates both snapping and slipping of roots
  - Function of soil conditions

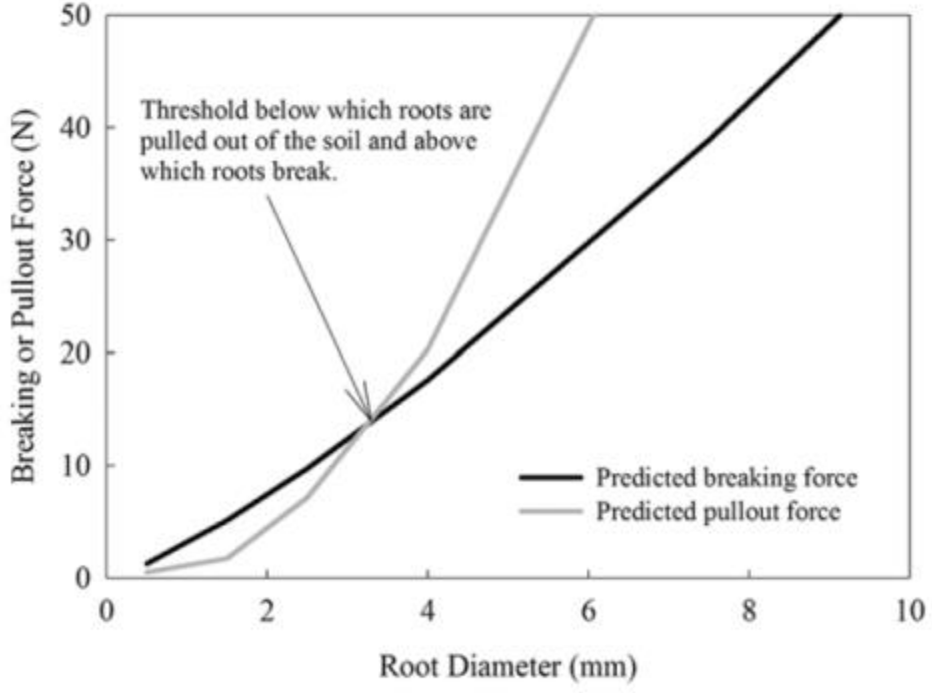


Figure 1. Graph showing estimated pullout versus breaking forces for river birch roots in a soil with strength of 6 kPa.

Pollen and Simon, 2005

RipRoot: Root Strength

- RipRoot fiber bundle approach, improves on perpendicular root models
  - Perpendicular root models overestimate strength, result in a maximum, all roots fail simultaneously

- Fiber Bundle Models
  - Assumes cascading failure of roots; when some roots fail, load is redistributed to remaining roots
  - Maximum load withstood by the group of fibers is less than the sum of individual strengths

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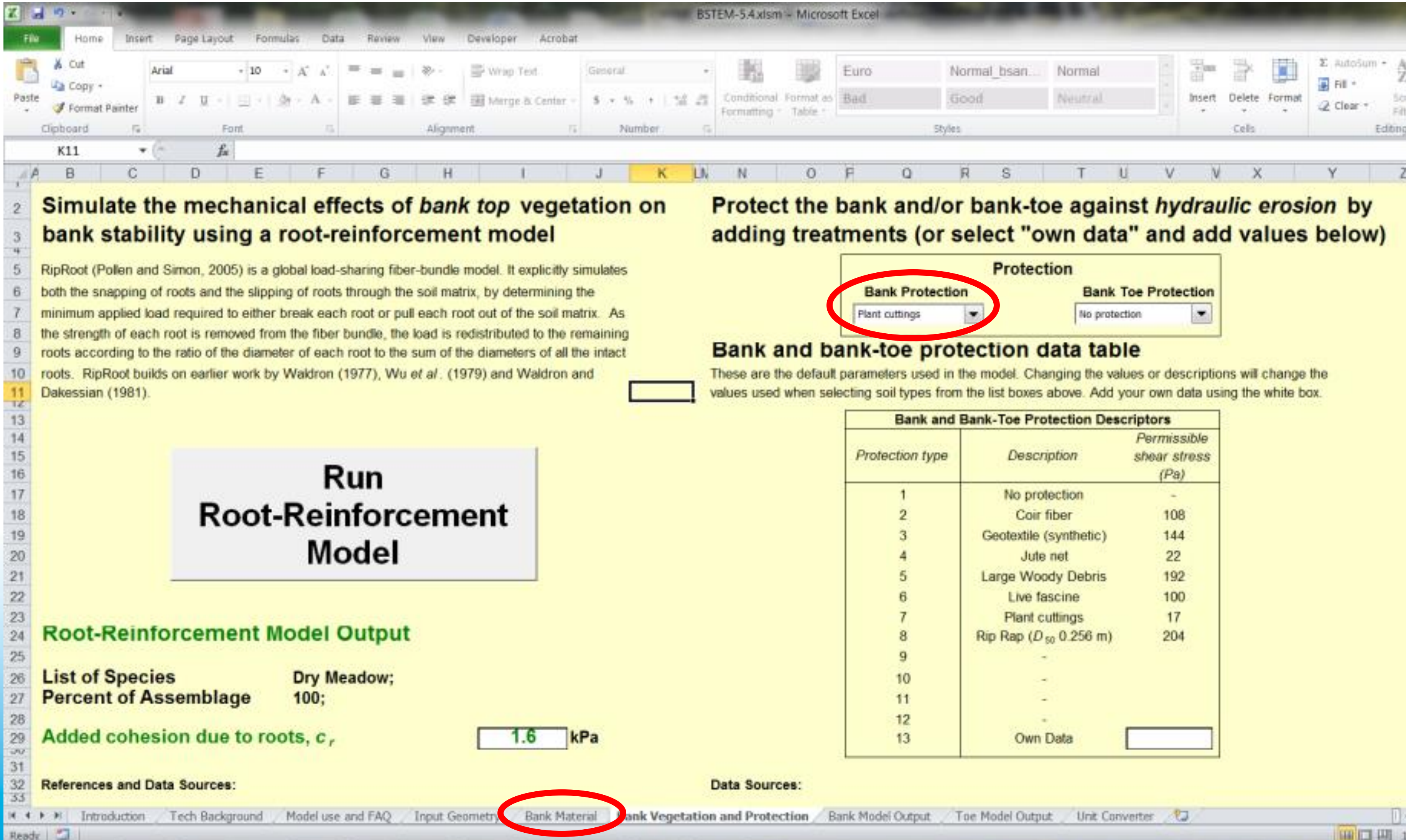
RipRoot: Input



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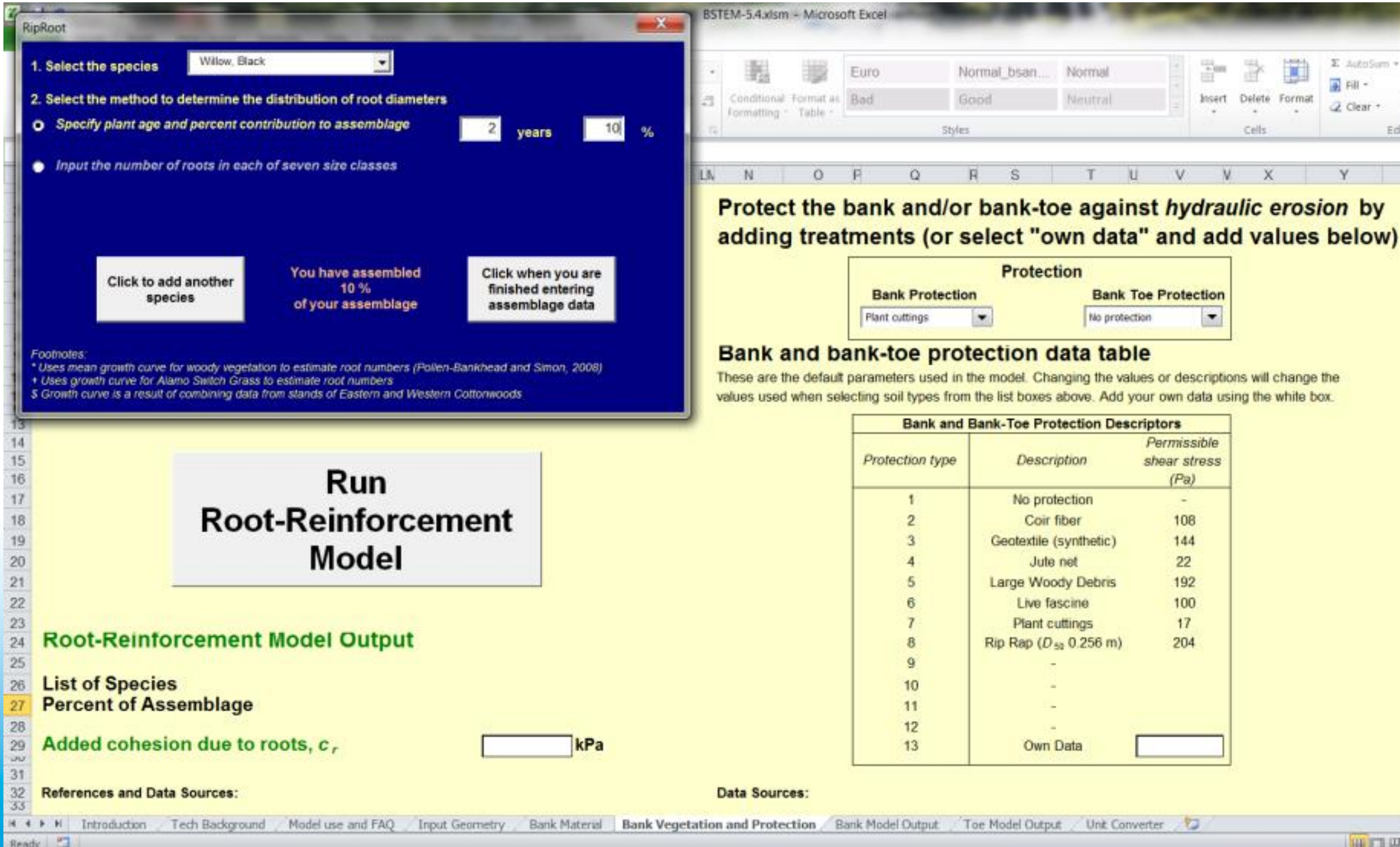
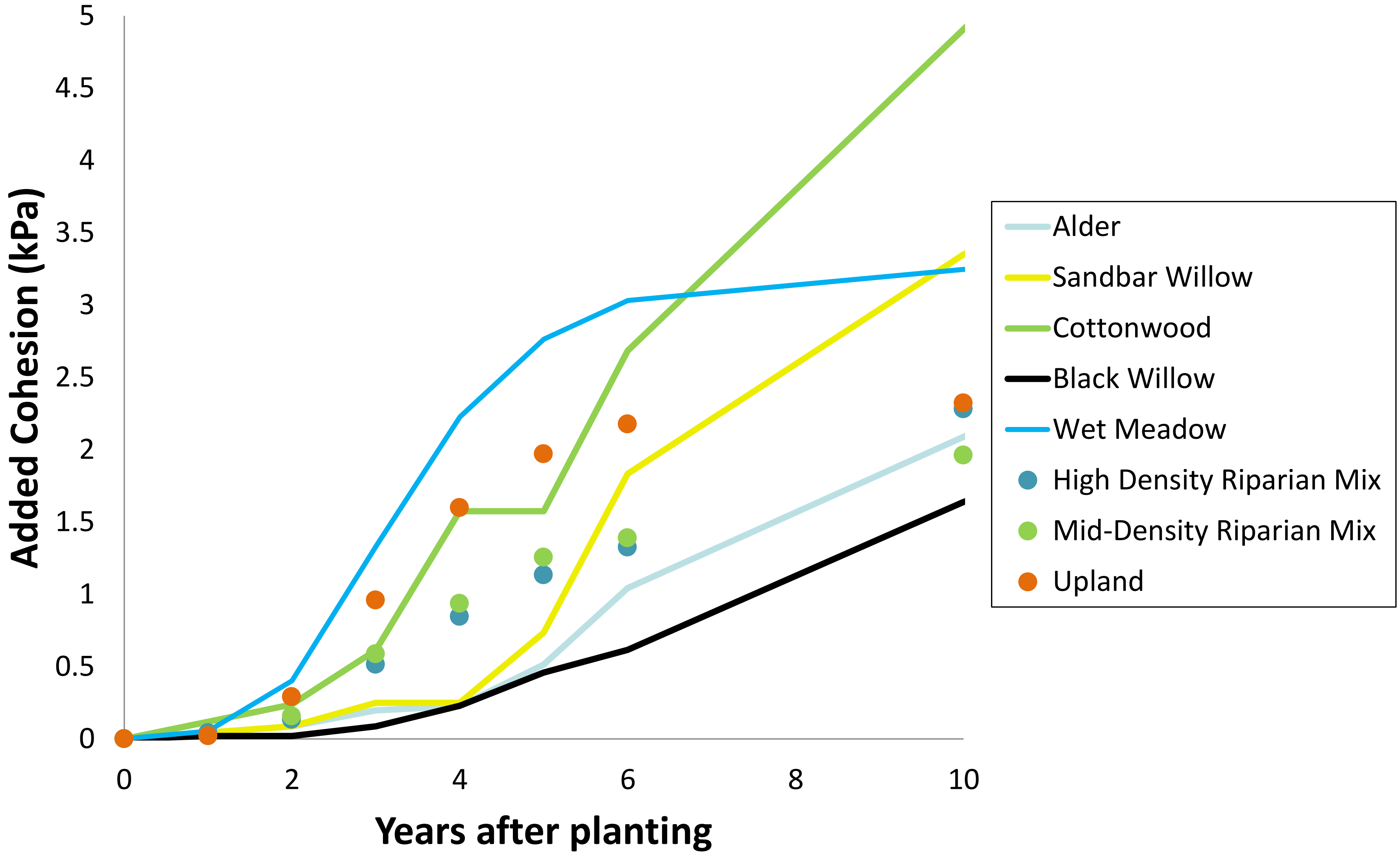
Riproot: Input



RipRoot: Added Cohesion



RipRoot: Added Cohesion

	High Density Riparian (kPa)	Mid Density Riparian (kPa)	Upland (kPa)
Year 1	0.04	0.02	0.02
Year 2	0.14	0.16	0.29
Year 3	0.51	0.59	0.96
Year 4	0.84	0.93	1.60
…			
Year 10	2.28	1.96	2.32
…			
Year 50	6.13	3.77	2.35

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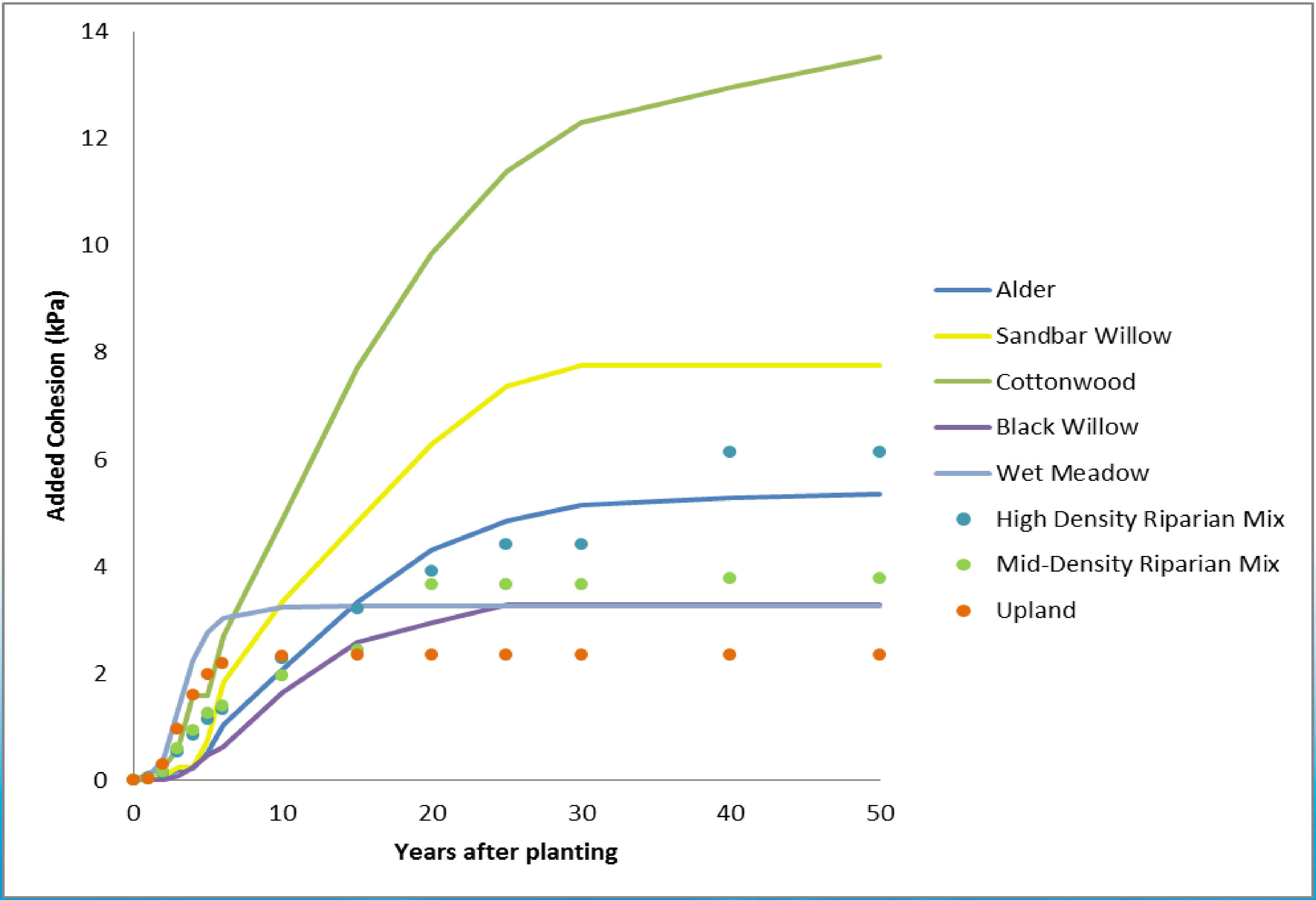
RipRoot: Added Cohesion



Future Work

- Look at potential bank erosion scenarios to determine if the added cohesion is enough to resist bank failure
- Can do this with BSTEM

- Representing multiple layers of vegetation in RipRoot (high density zone)

Preliminary Conclusions

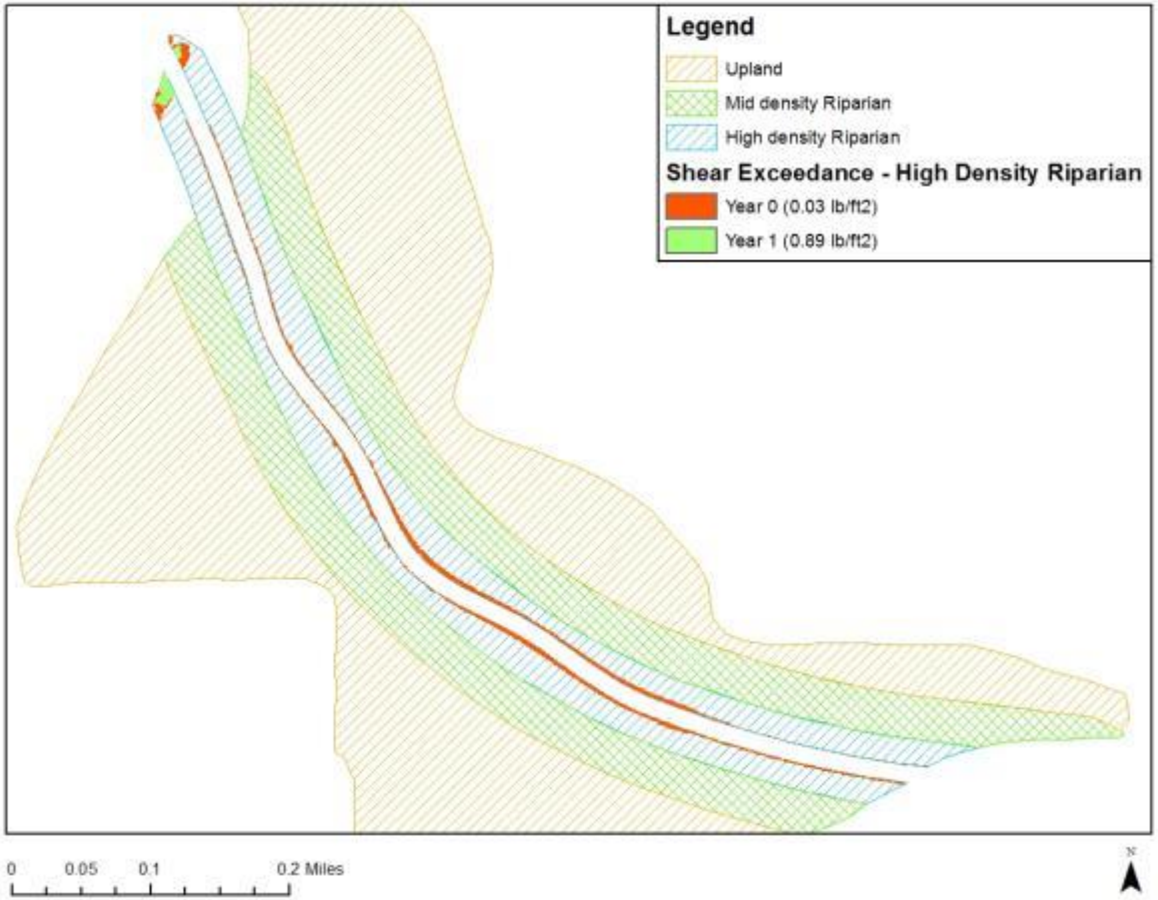
- Herbaceous understory layer expected to resist hydraulic shear / reduce erosion at 4,500 cfs
  - Susceptible to undercutting and nonuniformity
- Added cohesion due to roots is apparent within 2 – 4 years after planting
  - 40 years for high density zone to fully establish
  - 10 years for uplands to fully establish
- More work necessary to understand if this added cohesion is sufficient to resist bank failure scenarios


Questions?

EXTRA SLIDES

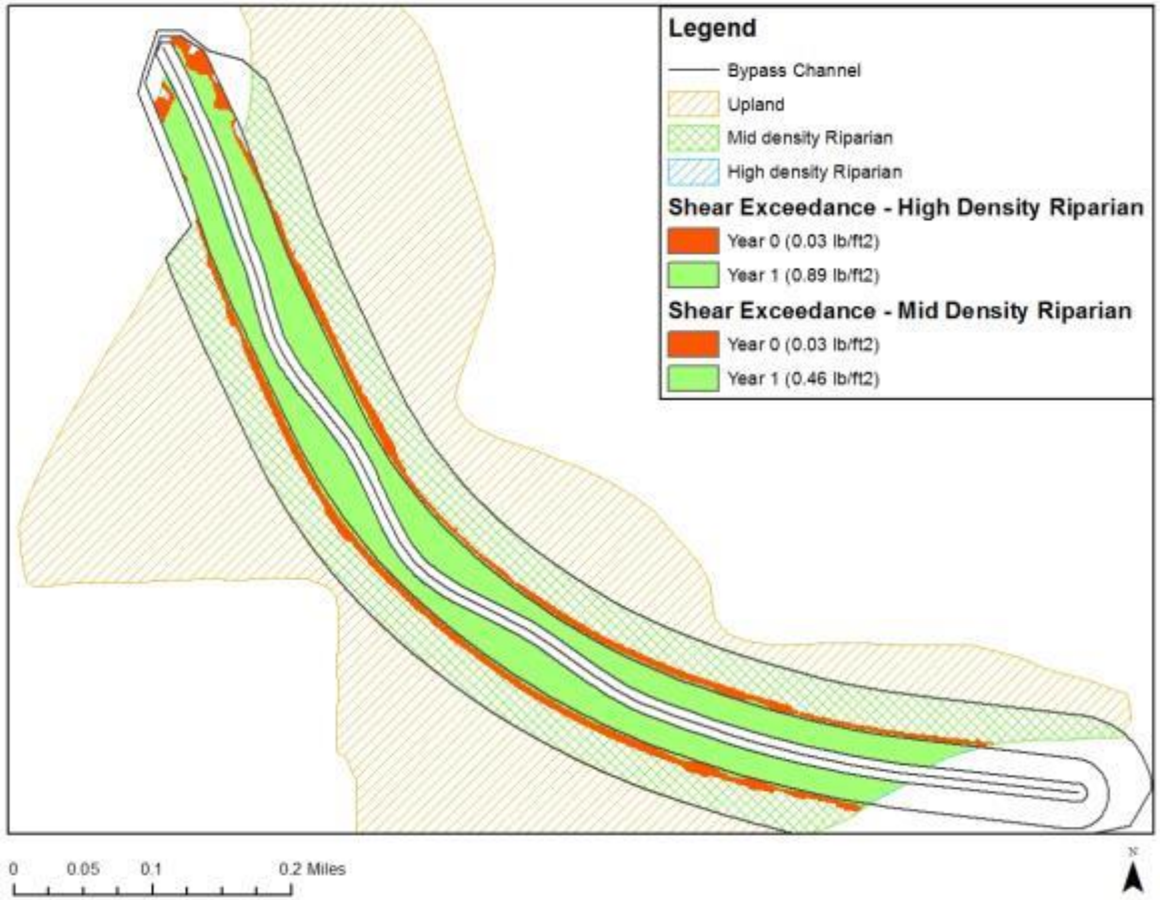
250 cfs

Critical Shear Exceedance at 250 cfs in Mendota Pool Bypass

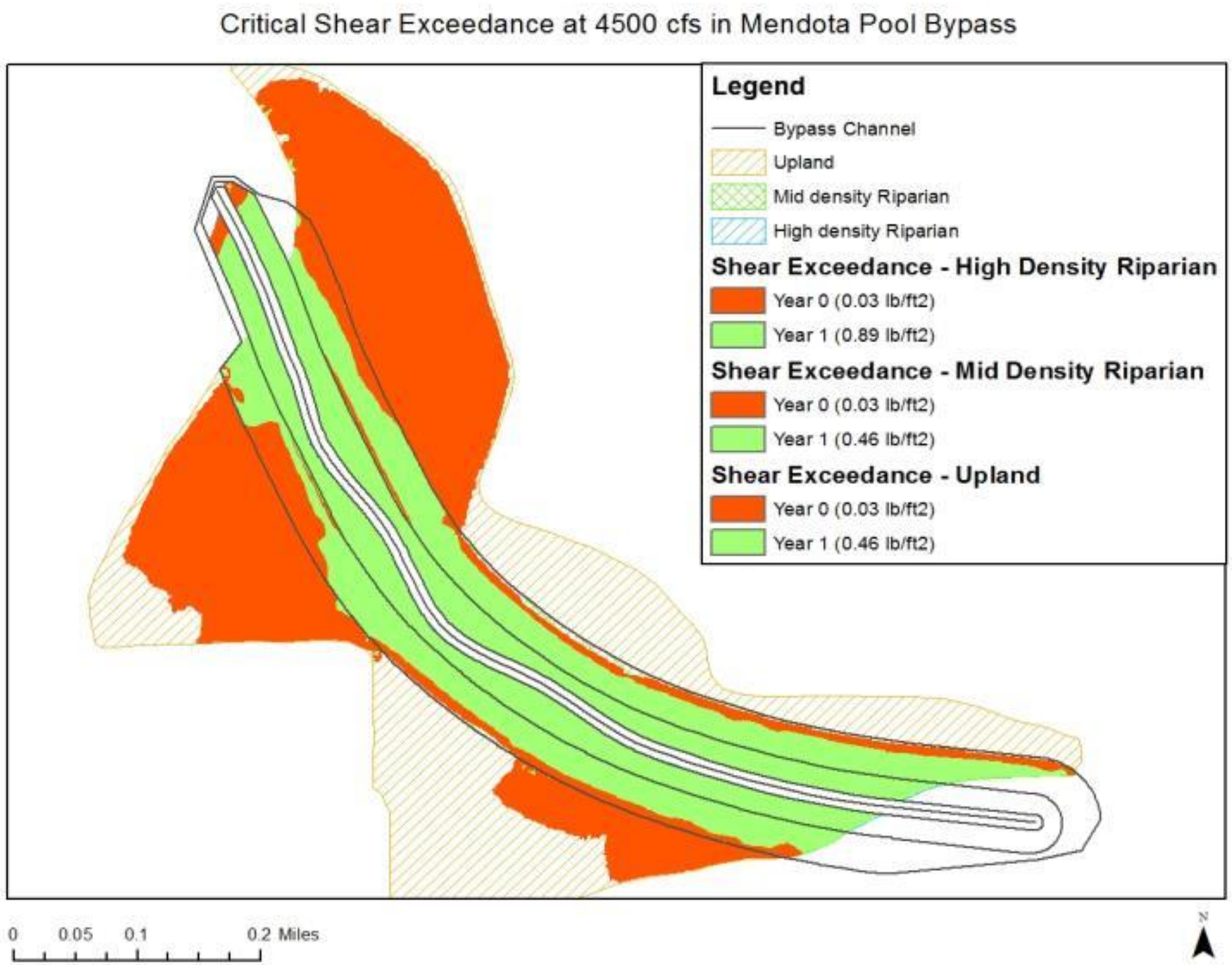


1200 cfs

Critical Shear Exceedance at 1200 cfs in Mendota Pool Bypass



How long for Vegetation to Establish?



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Other Factors

- Representing multiple layers of vegetation in RipRoot (high density zone)
- Localized high shear, at scales finer than the 2D model grid, could cause scour/erosion that is not represented in the 2-D hydraulic model
- …