

# San Joaquin River Restoration Program



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

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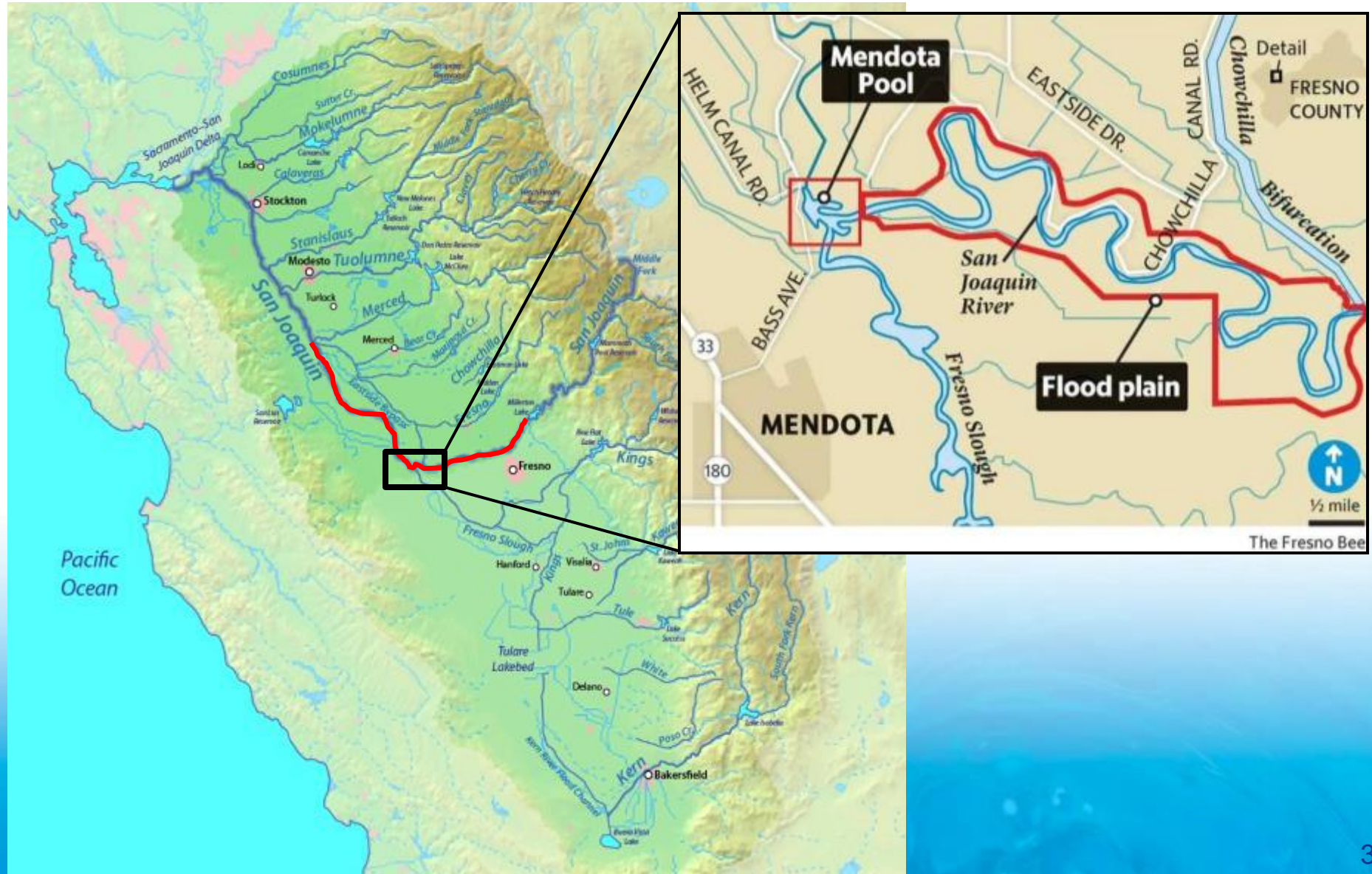
**CWEMF - April 12, 2016**

# 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.

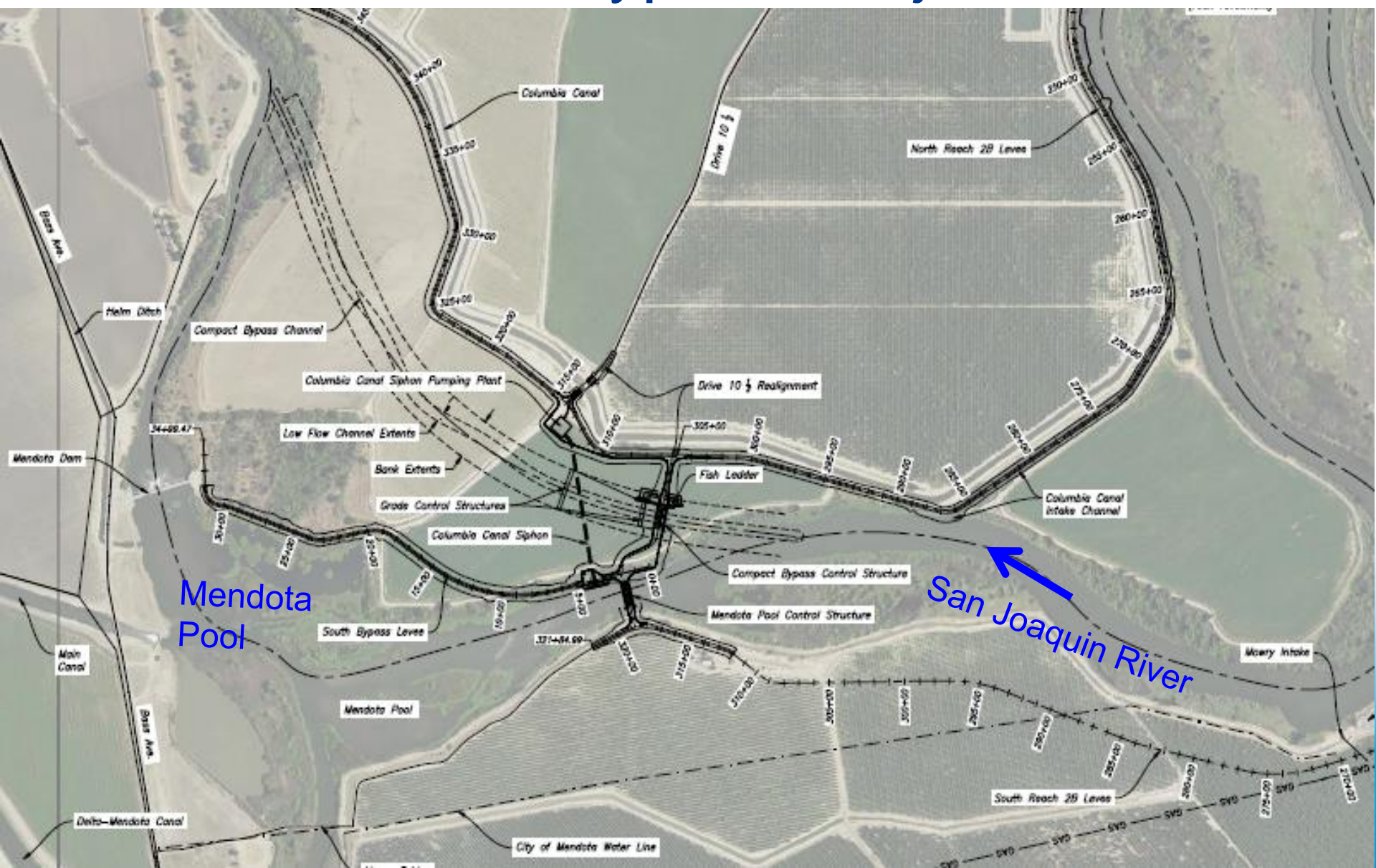


# SJRRP Project Area

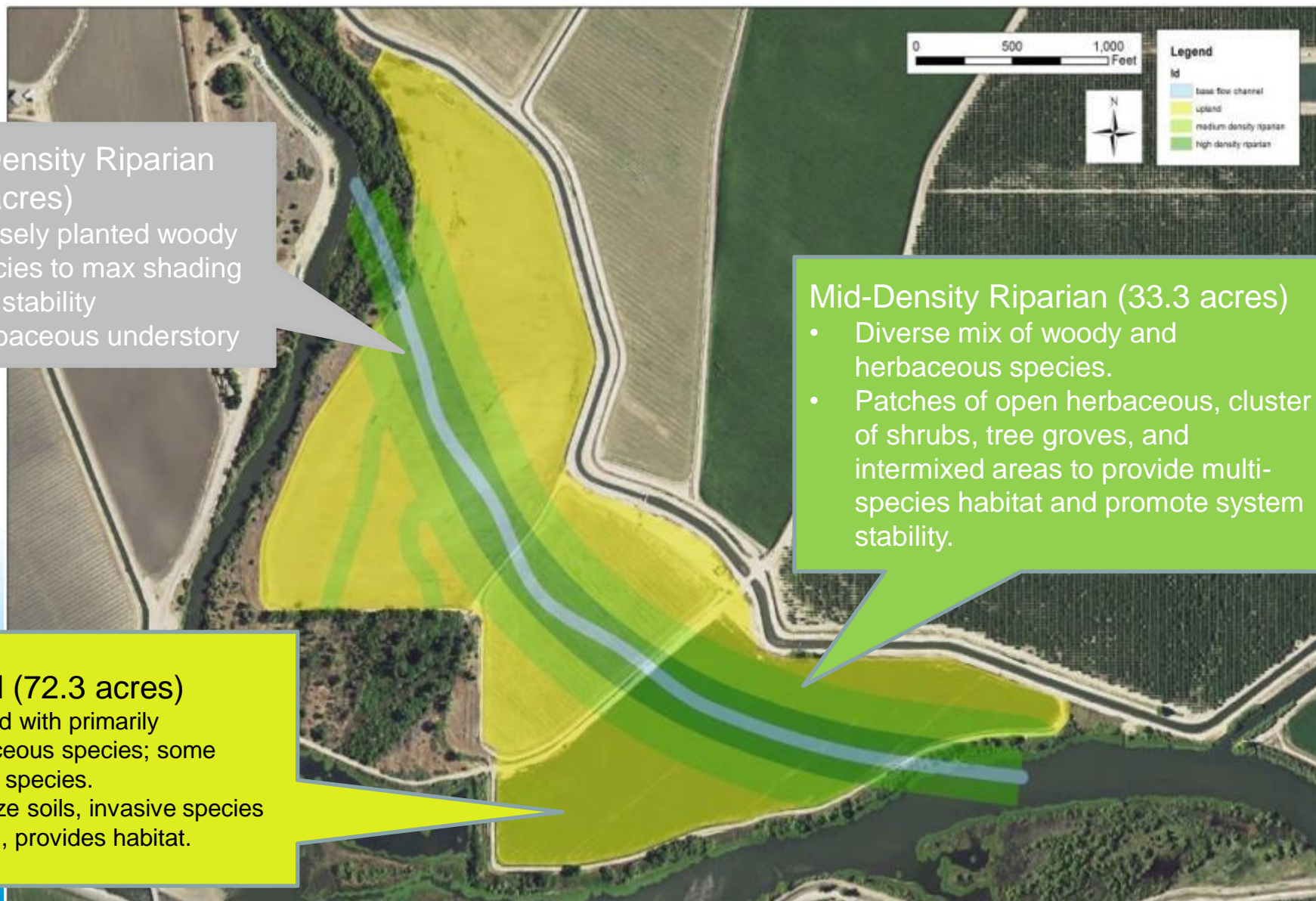




# Passage: The Mendota Pool Bypass Project



# 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

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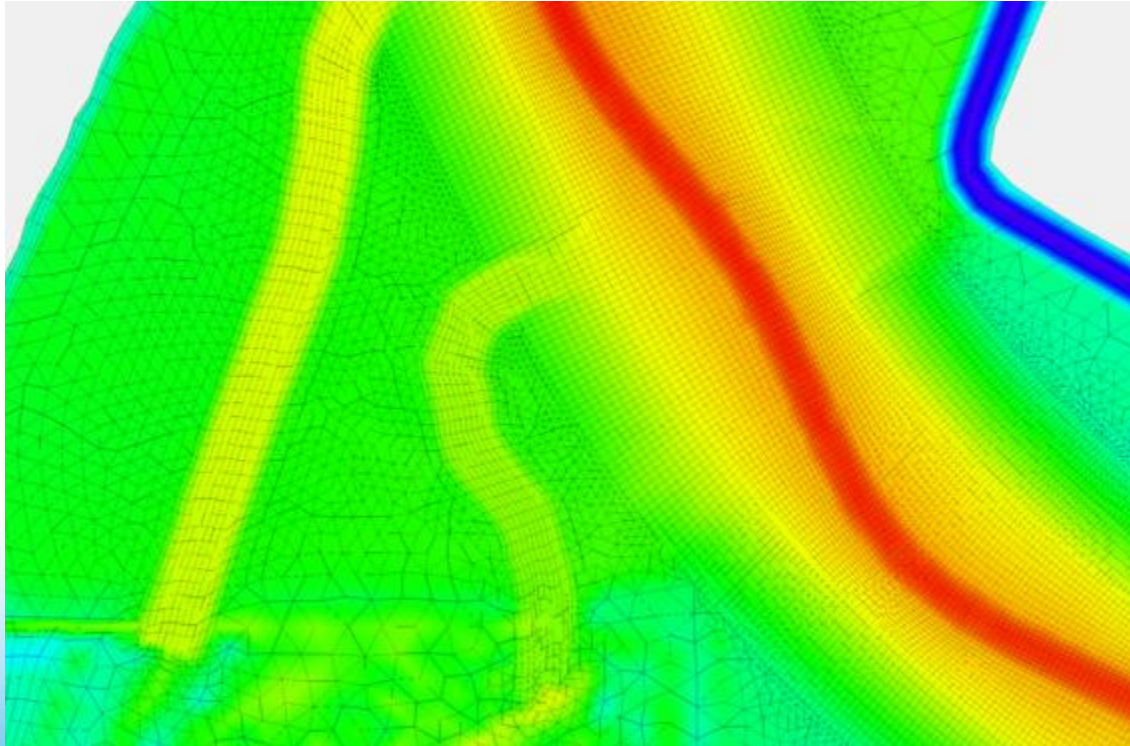
- Is vegetation sufficient to resist **erosion** and **undercutting** in the compact bypass, or is additional bank protection needed?
  - Calculate shear stresses within the bypass channel
  - Determine time required for vegetation establishment to minimize erosion and potential bank failure

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

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- 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

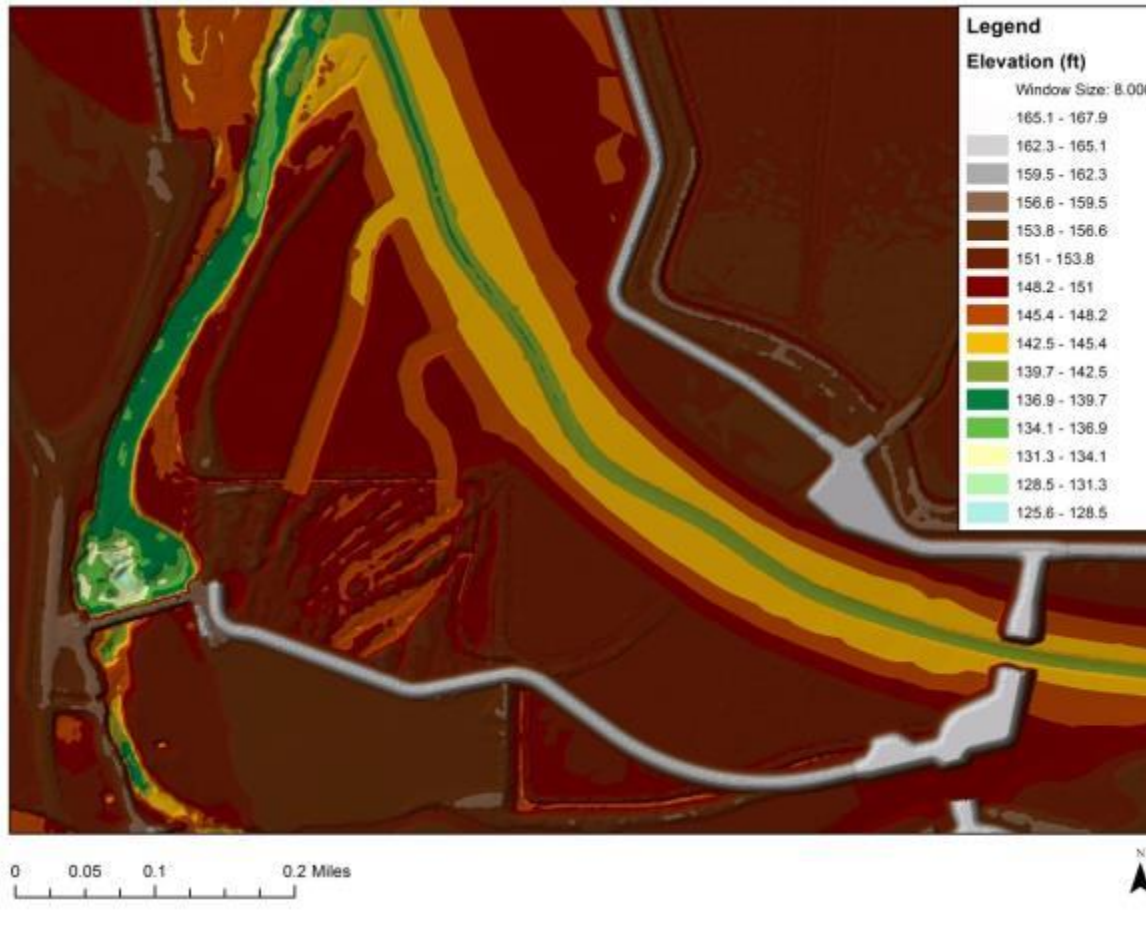
# SRH-2D: Mesh



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

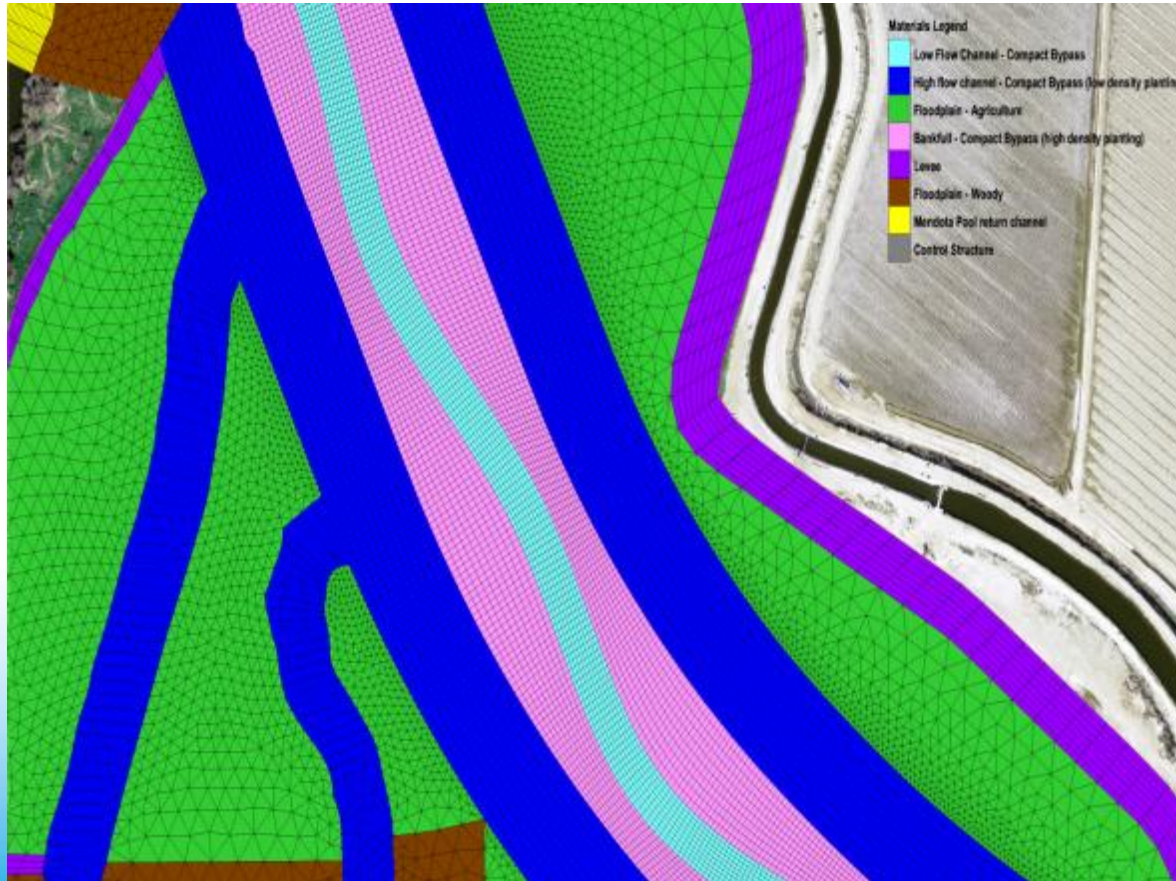


# SRH-2D: Terrain



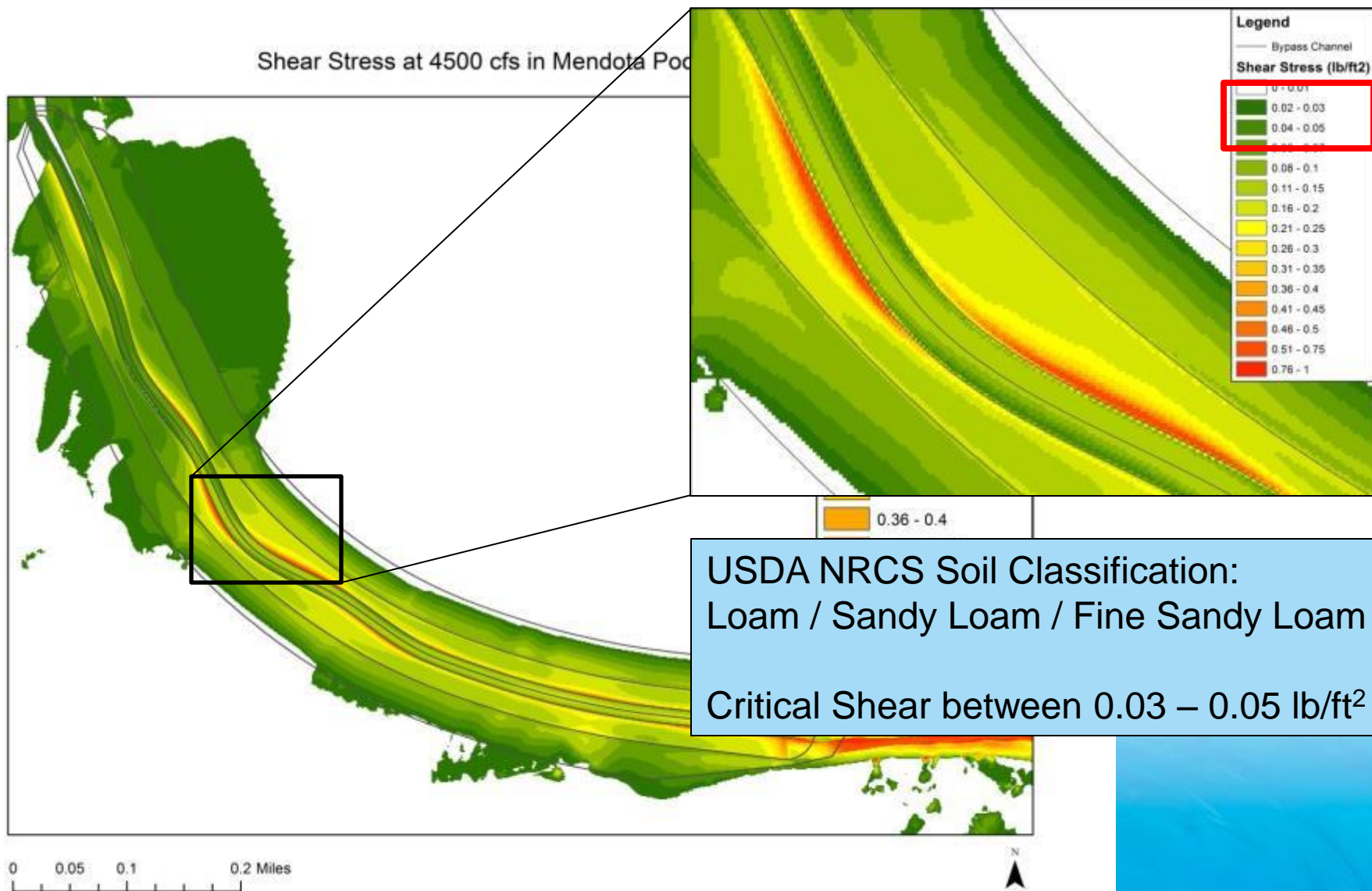
- Elevations from 2008 LiDAR and design geometry of channel
- Upstream incision and downstream aggradation approximated to remove abrupt transitions

# 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<sup>2</sup>





# 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)



# 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)	(m)
<b>Cool-season grasses</b>		
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
<b>Warm-season grasses</b>		
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

$$C_I = 2.5(h\sqrt{M})^{\frac{1}{3}}$$

(eq. 8-28)

where:

$h$  = the representative stem length

$M$  = the stem density in stems per unit area

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

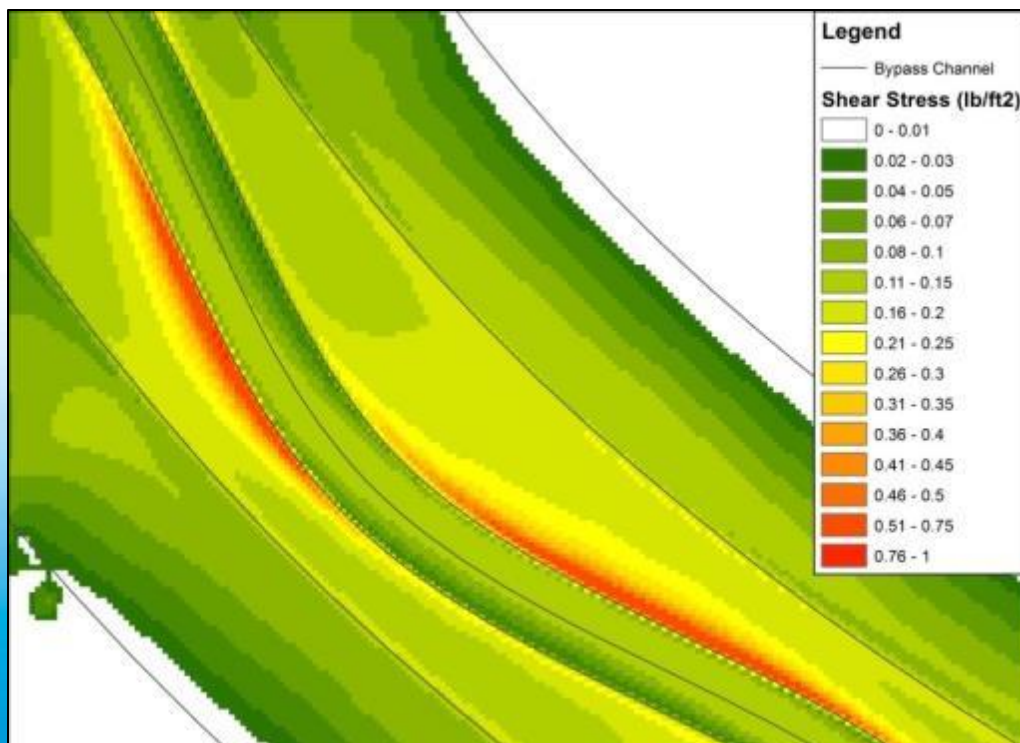
**Table 8-10** Properties of grass channel linings values (apply to good uniform stands of each cover)

Cover factor ( $C_F$ )	Covers tested	Reference stem density (stems/ft <sup>2</sup> )	Reference stem density (stems/m <sup>2</sup> )
0.90	Bermudagrass	500	5,380
	Centipede grass	500	5,380
0.87	Buffalograss	400	4,300
	Kentucky bluegrass	350	3,770
0.75	Blue grama	350	3,770
	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.

# Allowable Shear Stress

Stem Length (h) (ft)	Stem Density (M) (stems/ft <sup>2</sup> )	Allowable Stress ( $T_{va}$ ) (lb/ft <sup>2</sup> )
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



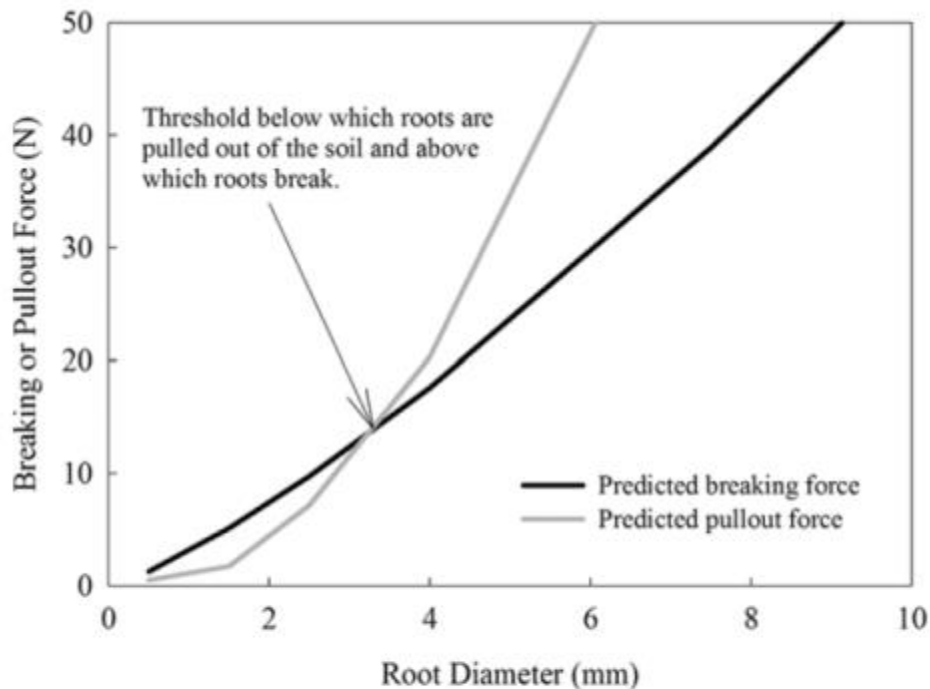
# Root Reinforcement Model: RipRoot (Pollen and Simon, 2005)

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- 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 ageOR
  - 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.





# RipRoot: Root Strength

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- 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

# RipRoot: Input

Microsoft Excel interface showing the RipRoot input spreadsheet. The spreadsheet is titled "BSTEM-5.4.xlsm".

**Simulation Description:**

Simulate the mechanical effects of *bank top* vegetation on bank stability using a root-reinforcement model

Protect the bank and/or bank-toe against *hydraulic erosion* by adding treatments (or select "own data" and add values below)

RipRoot (Pollen and Simon, 2005) is a global load-sharing fiber-bundle model. It explicitly simulates both the snapping of roots and the slipping of roots through the soil matrix, by determining the minimum applied load required to either break each root or pull each root out of the soil matrix. As the strength of each root is removed from the fiber bundle, the load is redistributed to the remaining roots according to the ratio of the diameter of each root to the sum of the diameters of all the intact roots. RipRoot builds on earlier work by Waldron (1977), Wu *et al.* (1979) and Waldron and Dakessian (1981).

**Protection Settings:**

Protection

Bank Protection: Plant cuttings (circled in red)

Bank Toe Protection: No protection

**Bank and bank-toe protection data table**

These are the default parameters used in the model. Changing the values or descriptions will change the values used when selecting soil types from the list boxes above. Add your own data using the white box.

Protection type	Description	Permissible shear stress (Pa)
1	No protection	-
2	Coir fiber	108
3	Geotextile (synthetic)	144
4	Jute net	22
5	Large Woody Debris	192
6	Live fascine	100
7	Plant cuttings	17
8	Rip Rap ( $D_{50}$ 0.256 m)	204
9	-	-
10	-	-
11	-	-
12	-	-
13	Own Data	<input type="text"/>

**Run Root-Reinforcement Model**

**Root-Reinforcement Model Output**

List of Species: Dry Meadow;  
Percent of Assemblage: 100;

Added cohesion due to roots,  $c_r$ :  kPa

**References and Data Sources:**

Data Sources:

Navigation tabs: Introduction, Tech Background, Model use and FAQ, Input Geomet, **Bank Material** (circled in red), Bank Vegetation and Protection, Bank Model Output, Toe Model Output, Unit Converter

# Riproot: Input

RipRoot

1. Select the species

2. Select the method to determine the distribution of root diameters

Specify plant age and percent contribution to assemblage  years  %

Input the number of roots in each of seven size classes

You have assembled 10 % of your assemblage

Footnotes:  
 \* Uses mean growth curve for woody vegetation to estimate root numbers (Pollen-Bankhead and Simon, 2008)  
 + Uses growth curve for Alamo Switch Grass to estimate root numbers  
 ‡ Growth curve is a result of combining data from stands of Eastern and Western Cottonwoods

BSTEM-5.4.xlsm - Microsoft Excel

Conditional Formatting - Table - Euro Normal\_bsan... Normal Bad Good Neutral Insert Delete Format AutoSum Fill Clear

LM N O P Q R S T U V W X Y

**Protect the bank and/or bank-toe against hydraulic erosion by adding treatments (or select "own data" and add values below)**

**Protection**

Bank Protection:  Bank Toe Protection:

**Bank and bank-toe protection data table**

These are the default parameters used in the model. Changing the values or descriptions will change the values used when selecting soil types from the list boxes above. Add your own data using the white box.

Bank and Bank-Toe Protection Descriptors		
Protection type	Description	Permissible shear stress (Pa)
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9	-	-
10	-	-
11	-	-
12	-	-
13	Own Data	<input type="text"/>

**Run Root-Reinforcement Model**

**Root-Reinforcement Model Output**

List of Species  
 Percent of Assemblage

Added cohesion due to roots,  $c_r$   kPa

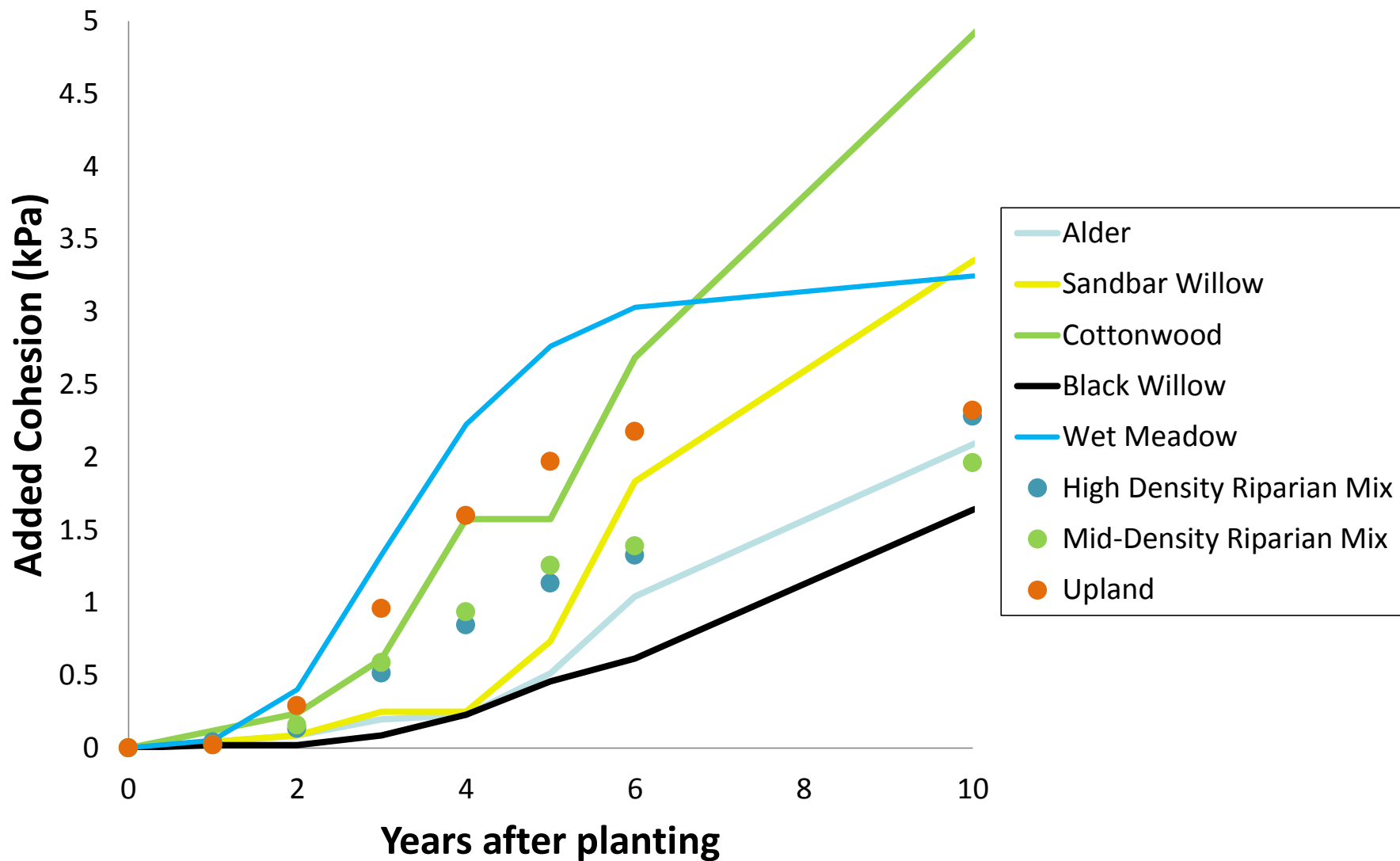
References and Data Sources:

Data Sources:

Introduction Tech Background Model use and FAQ Input Geometry Bank Material Bank Vegetation and Protection Bank Model Output Toe Model Output Unit Converter



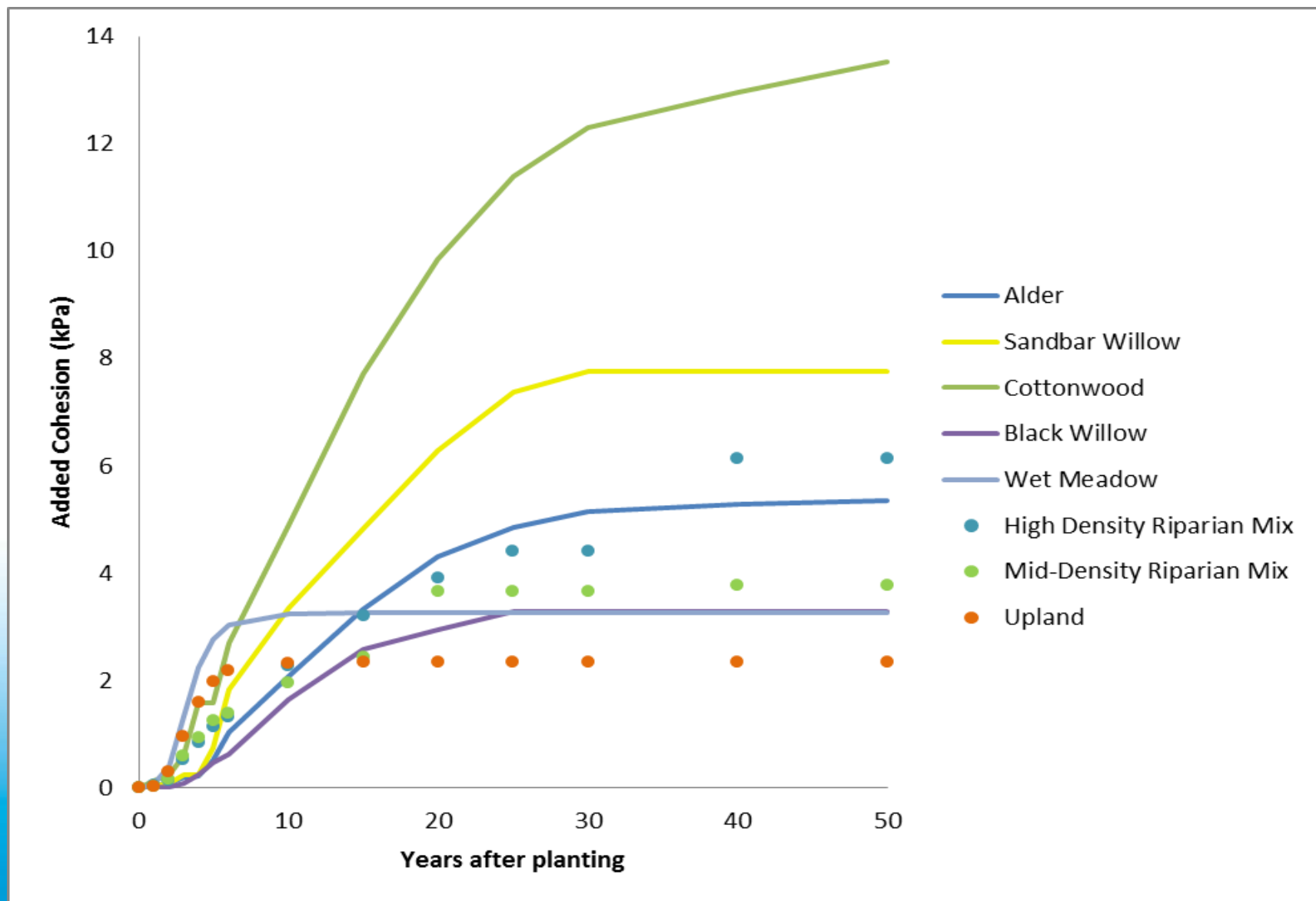
# RipRoot: Added Cohesion



# RipRoot: Added Cohesion

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

# RipRoot: Added Cohesion







# Future Work

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- 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

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- 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?





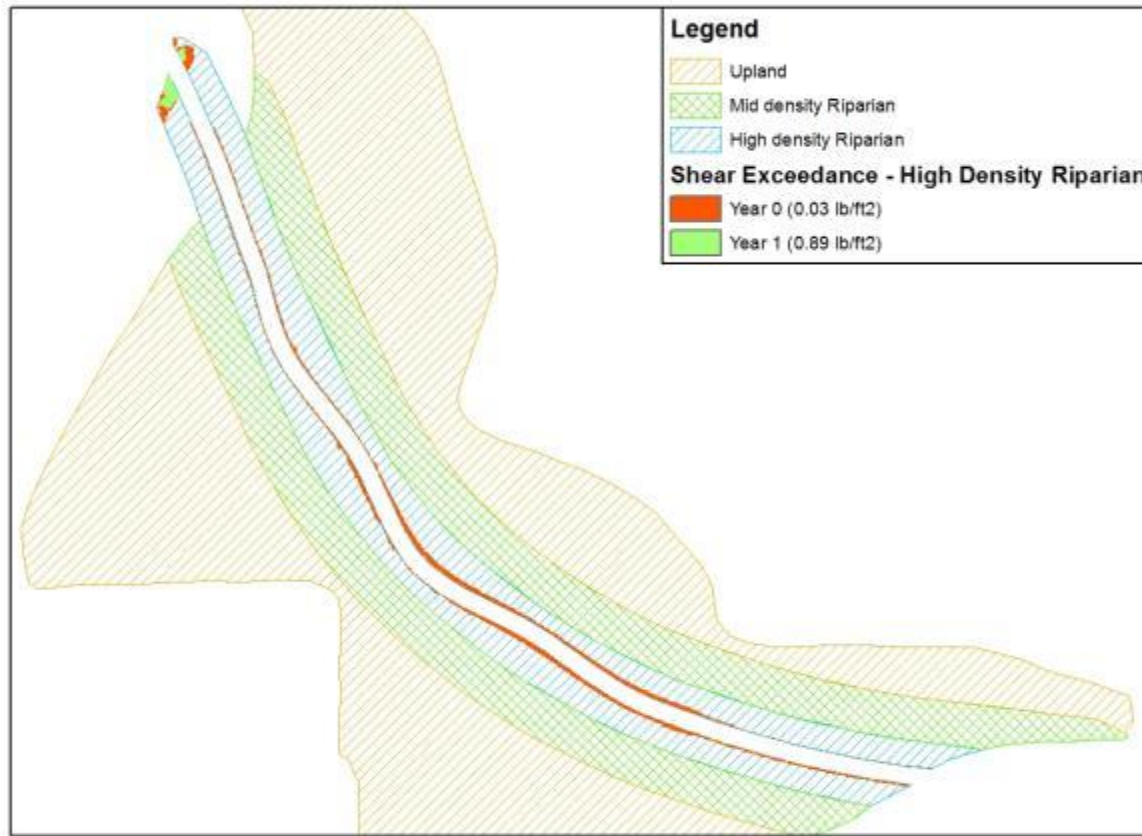


# EXTRA SLIDES



# 250 cfs

Critical Shear Exceedance at 250 cfs in Mendota Pool Bypass



0 0.05 0.1 0.2 Miles





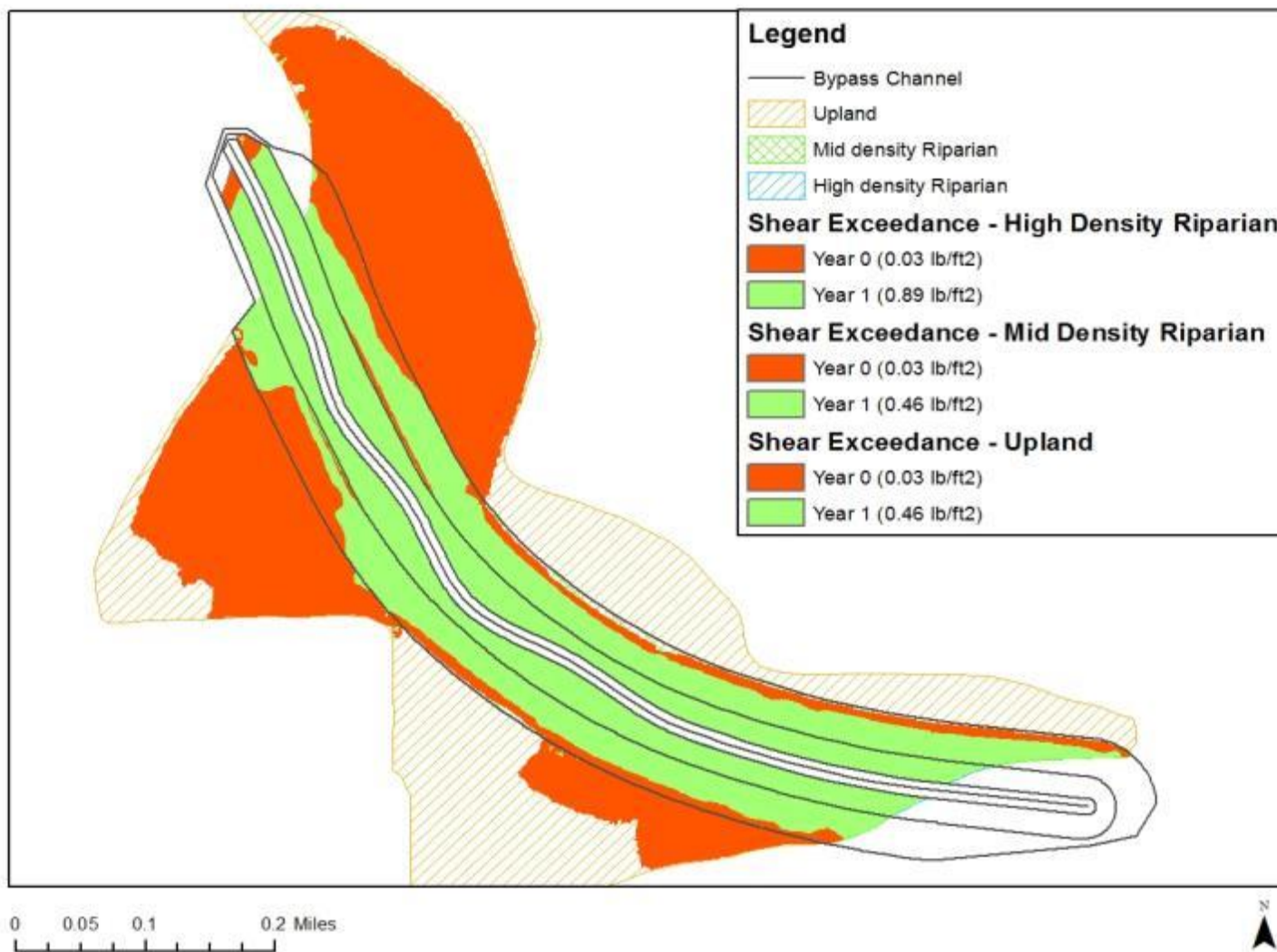
# 1200 cfs

Critical Shear Exceedance at 1200 cfs in Mendota Pool Bypass



# How long for Vegetation to Establish?

Critical Shear Exceedance at 4500 cfs in Mendota Pool Bypass







# Other Factors

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- 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
- ...