The Effects of Woody Vegetation on Levees

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US Army Corps of Engineers
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Problem Statement

What is driving the research?

The need for scientific support to quantify effects of woody vegetation on levees

- **Nationwide levee inspection in Feb 2007, 122 levees were found maintenance deficient; many concerned woody vegetation**
- **USACE-HQ engaged ERDC to perform extensive literature review of the effects of woody vegetation on levees**
- **Literature review identified research gaps leading to present effort**

Methodology

- Task 1- Conduct an extensive literature review
  - Compilation of documents, government reports, international guidance, and journal articles concerning woody vegetation on levees
- Task 2- Select study sites
  - Consider levee geometry, soils, geology, geographic setting, geotechnical reports, and vegetation type

<u>Site Characterization</u>
- Sacramento, CA
- Burlington, WA
- Portland, OR
- Albuquerque, NM

<u>Site Assessments</u>
- Danville, PA
- Jacksonville, FL
- New Orleans, LA
- Lake Providence, LA

Methodology

- Task 3- Field Data Collection
  - Tool selection based on published research and consultation with experts in academia and private industry
  - Driven by model input requirements
  - Tree properties and identification
    - Record tree species and their specific properties
    - Use existing literature to determine tree age, evapotranspiration, and general root extent
  - Root architecture
    - Geophysical and in situ root mapping will be used to define root architecture
  - Root reinforcement for slope stability
    - Three characteristics of slope stability: Unit weight of soil (w), soil cohesion (c), and internal friction angle (Φ)
  - Soil properties
    - If available, existing documents will contribute to the levee profile
    - Permeability and soil moisture will be determined by field measurements

Methodology

- Task 4 - Numerical model simulation
  - ▶ Modeling for sensitivity analysis
  - ▶ Deformation analysis

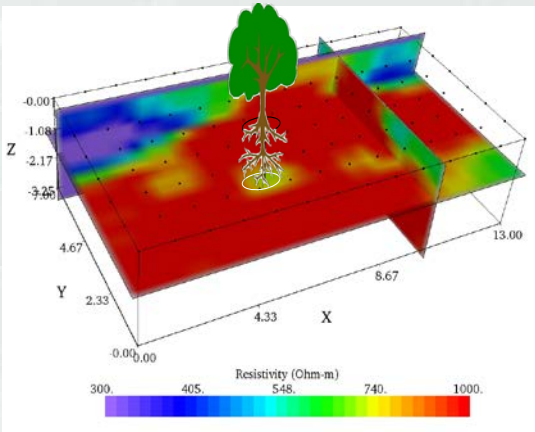
Task 3- Field Data Collection

- Root architecture
- Root reinforcement for slope stability
- Soil properties

Field Data → Numerical Models

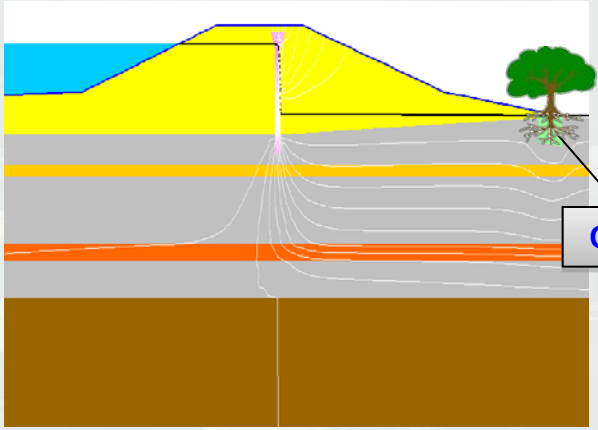
Root Architecture

- ❑ Defines cohesive root ball
- ❑ Provides a map of soil electrical resistivity values which can be used to infer soil type, distribution, moisture



Depth = 1.25m

Pocket Levee, Sacramento, CA
3D Resistivity field results
ERDC Veg Field Team, 2009



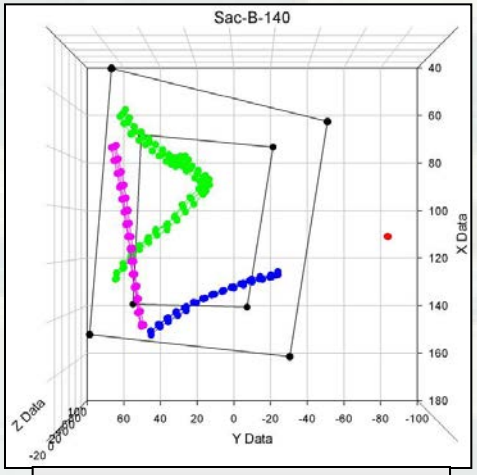
Pocket Levee, Sacramento, CA
Seepage analysis
ERDC Veg Model Team, 2010

Field Data ➡ Numerical Models

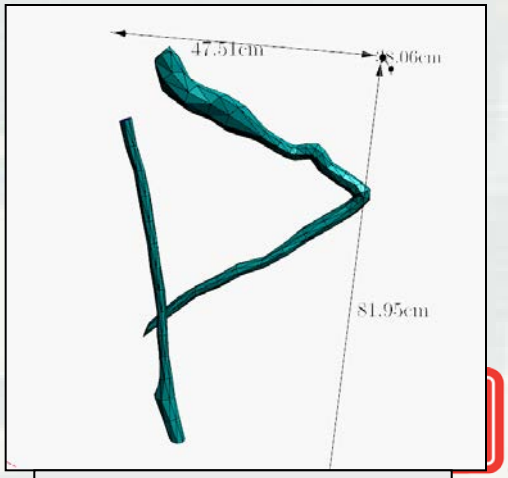
Root Architecture

- ❑ Root volume – primary calibration parameter for geophysical surveys
- ❑ Surface area – assessment of uptake rates
- ❑ Root area ratio – calibration of geophysical surveys, evaluation of root distribution within the soil

Pocket Levee, Sacramento, CA
Exposed roots
ERDC Veg Field Team 2009



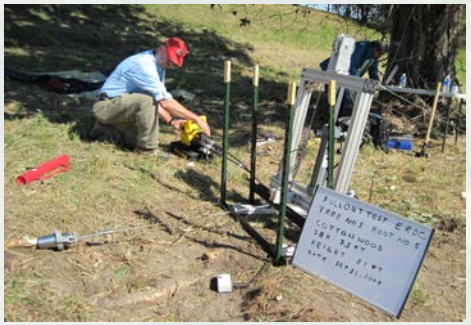
Pocket Levee, Sacramento, CA
Polhemus 3D digitized roots
ERDC Veg Field Team 2009

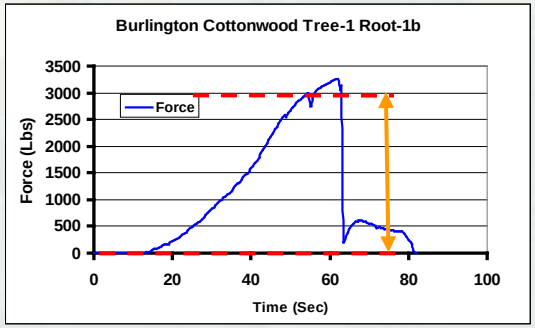


Pocket Levee, Sacramento, CA
3D geometry of roots
ERDC Veg Model Team 2010

Field Data ➡ Numerical Models

Root Reinforcement for Slope Stability

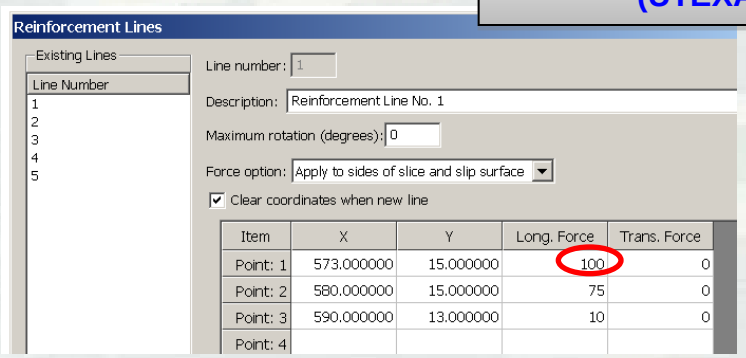


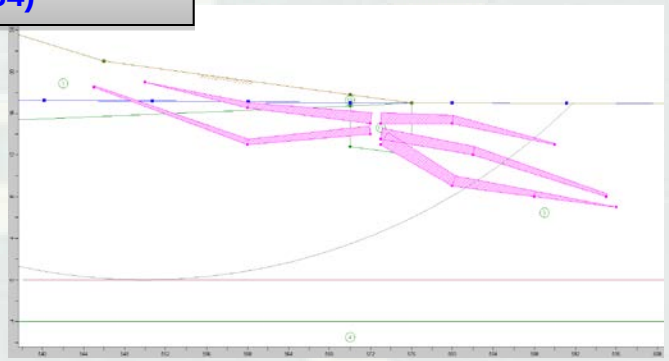


Root Length = 30 ft
Force = 3000 lbs
Force/Root Length = 100 lbs/ft

Burlington, WA
Root pullout field results
ERDC Veg Field Team 2009

Slope Stability Model (UTEXAS4)





Pocket Levee, Sacramento, CA
ERDC Veg Model Team 2010

Field Data ➡ Numerical Models

Soil Properties

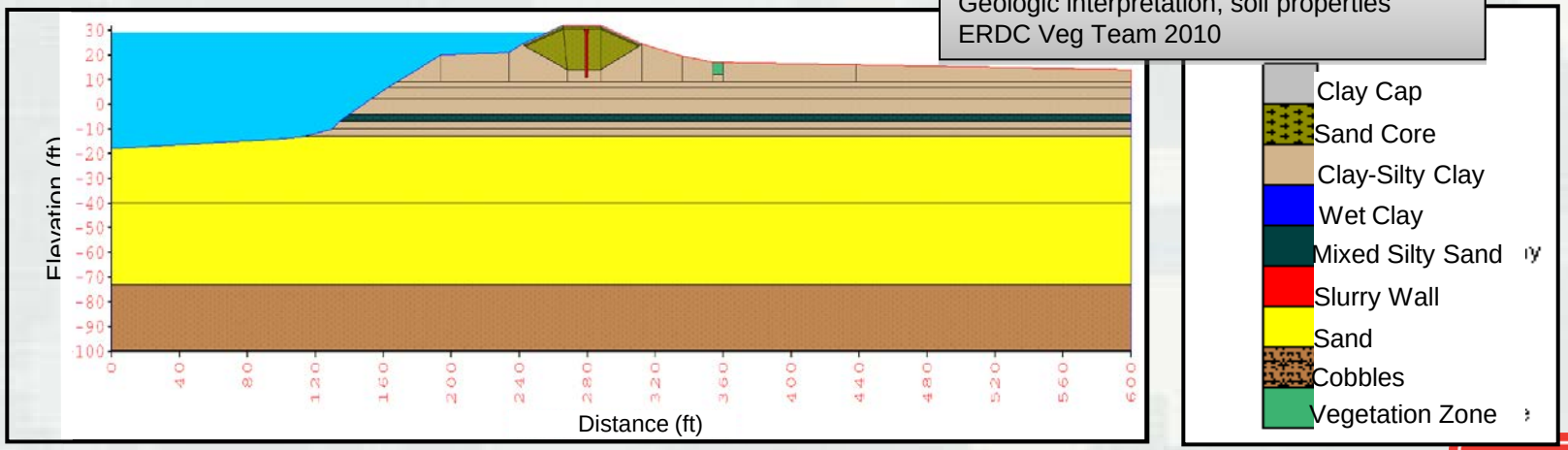
- ❑ Permeability and geologic interpretation used in levee profile

Burlington, WA
Soil collection
ERDC Veg Field Team 2010

DRAFT MATERIAL PROPERTIES
ERDC Model at Station 292+00
based on Borehole data from CPT-WM-016 and other published references

Layer No.	Layer Name	Layer Thickness Elev (ft)	Soil Class	Kv	Kh	Kv	Kh
				cm/s	cm/s	ft/day	ft/day
1	Clay Cap *	32 to 30	CL	1.00E-05	1.00E-05	2.83E-02	2.83E-02
2	CUT-OFF WALL	31.5 to 11.0	Soil/Bentonite?	1.00E-06	1.00E-06	2.83E-03	2.83E-03
3	LEVEE	30 to 14	SP	5.00E-03	2.00E-02	1.42E+01	5.67E+01
4	BLANKET	14 to 9	Clay,Silty Clay	1.50E-03	9.50E-03	4.25E+00	2.69E+01
5	BLANKET **	9 to 7	Wet Clay	1.50E-03	9.50E-03	4.25E+00	2.69E+01
6	BLANKET	7 to - 4	Clay,Silty Clay	1.50E-03	9.50E-03	4.25E+00	2.69E+01
7	BLANKET	- 4.0 to - 7.0	Mixed sand and clay	5.00E-04	9.00E-03	1.42E+00	2.55E+01
8	BLANKET	- 7.0 to - 13	Clay,Silty Clay	1.50E-03	9.50E-03	4.25E+00	2.69E+01
9	FOUNDATION	- 13 to - 73.0	Sand	1.00E-03	2.00E-02	2.83E+00	5.67E+01
10	FOUNDATION	- 73 to - 100.0	GP	1.00E-03	5.00E-02	2.83E+00	1.42E+02
11	Vegetation Zone	17 to 12	Clay,Silty Clay	1.50E-02	9.50E-01	4.25E+01	2.69E+03

Burlington, WA
Geologic interpretation, soil properties
ERDC Veg Team 2010



Sacramento, CA - Site B Station 292+60 Seepage Analysis Geologic Model

	River System	Levee System	Resistivity (2-D/3-D)	Ground Penetrating Radar (GPR)	Electromagnetics (EM)	Root Characterization (Quantitative)	Root Survey (Qualitative)	Root Pullout	In Situ Soil Parameters	Levee Geometry, visual assessment
New Orleans, LA	Mississippi (outfall canals)	17th St Canal	√	√	√	√	√	√		√
Sacramento, CA	Sacramento	Pocket	√	√	√	√	√	√	√	√
Burlington, WA	Skagit		√	√	√	√	√	√	√	√
Portland, OR	Columbia		√	√	√	√	√	√	√	√
Albuquerque, NM	Rio Grande	Alb West	√		√	√	√	√	√	√
Mollicy Farms, LA	Ouachita									√
Lake Providence, LA	Lake Providence									√
Lake Providence, LA	Mississippi									√
Jacksonville, FL	St John's		√							√
Danville, PA	Susquehanna									√
Ft Worth, TX	Trinity		√				√			√

√ Completed
√ Planned

Resistivity Provides information on the spatial extent and depth of the root system, depth of water table, resistivity of the soil (general soil type)

GPR Provides information on the spatial extent and depth of the root system, depth of water table. Provides some limited delineation of individual roots.

Electromagnetics Provides information on the spatial extent and depth of the root system, depth of water table, conductivity of the soil (general soil type)

Root Characterization Provides indepth information on the spatial extent and depth of the root system by exposing the roots. Allows capturing 3D digital data of the root system.

Root Survey Provides for a general observation of the root system in terms of measurements, notes, pictures, etc.

Insitu Soil Parameters Measurement of important soil properties in and around the root system to include permeability, moisture content.

Levee Geometry, Visual Assessment Site reconnaissance to collect any soils data or other information from the District, take notes, pictures, etc.

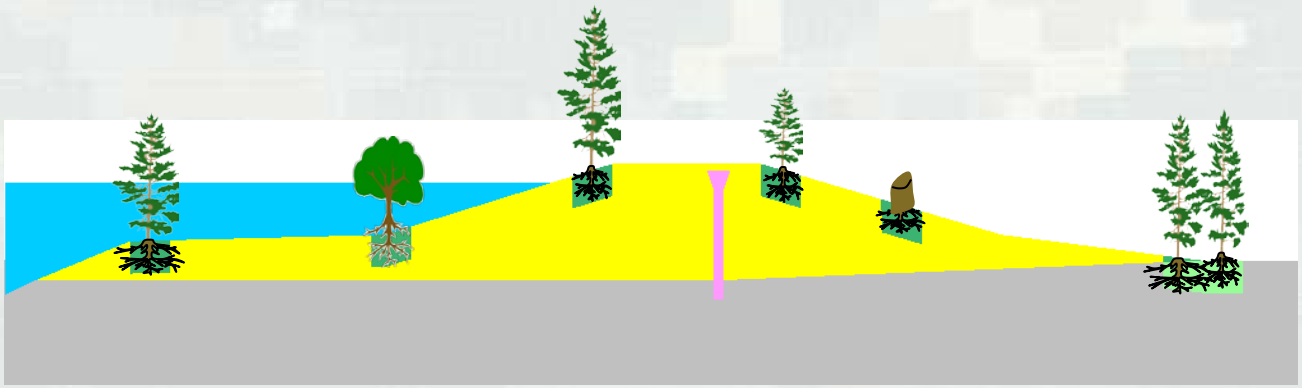
Task 4 Numerical Model Simulation

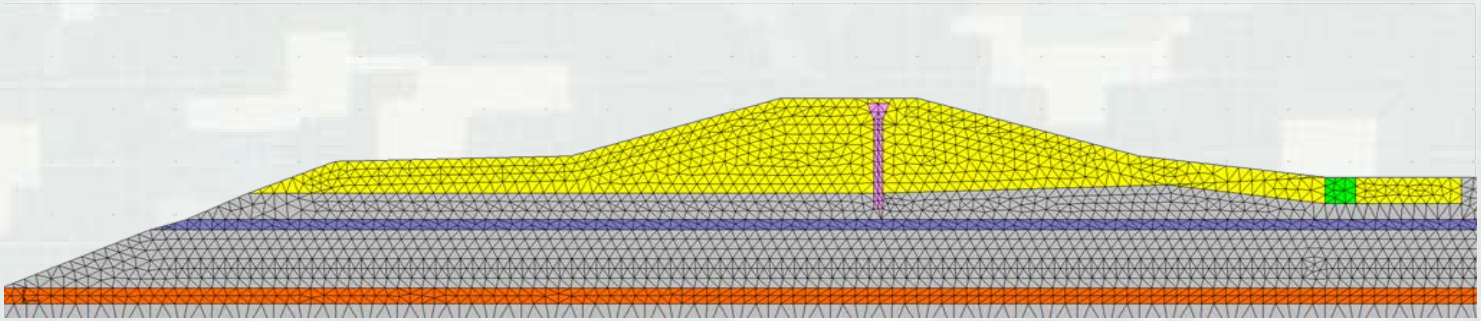
<u>Purpose of Modeling Effort</u>

- Mechanism of data synthesis
- Ties into standard design procedure
- Provides quantitative assessment of competing factors
- Results shown here are to illustrate methods

Numerical Model Simulation

2-D Seepage





Pocket Levee, Sacramento, CA
2D Mesh generation
ERDC Veg Model Team 2010

Modeling for Sensitivity Analyses

2-D Seepage

Pocket Levee, Sacramento, CA
Permeability variation
Flow direction and velocity
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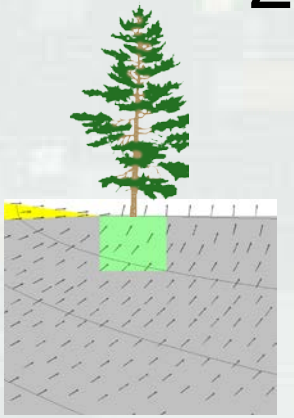
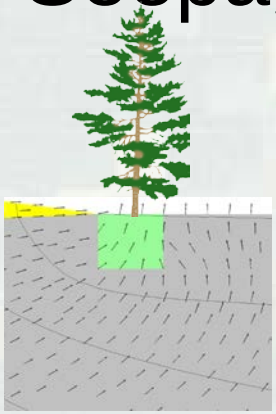
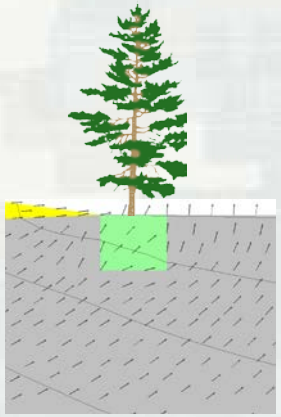


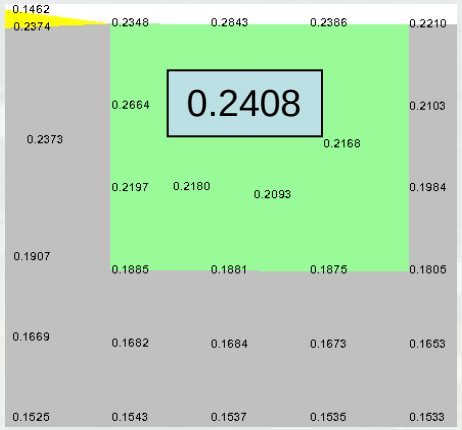
$k_{veg} = k_{no\text{-}veg}$

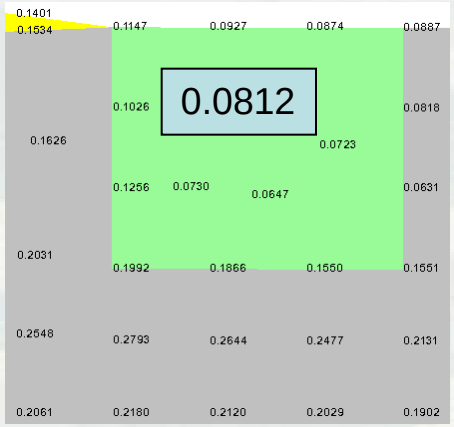


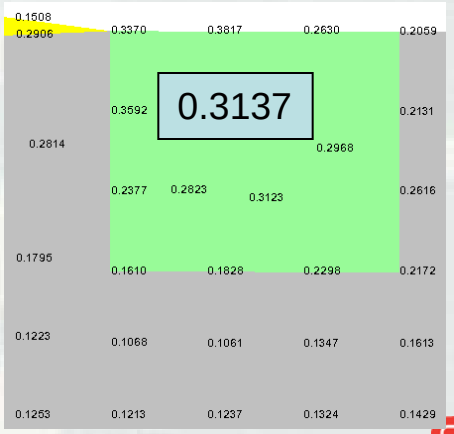
$k_{veg} = 10k_{no\text{-}veg}$



$k_{veg} = 0.01k_{no\text{-}veg}$



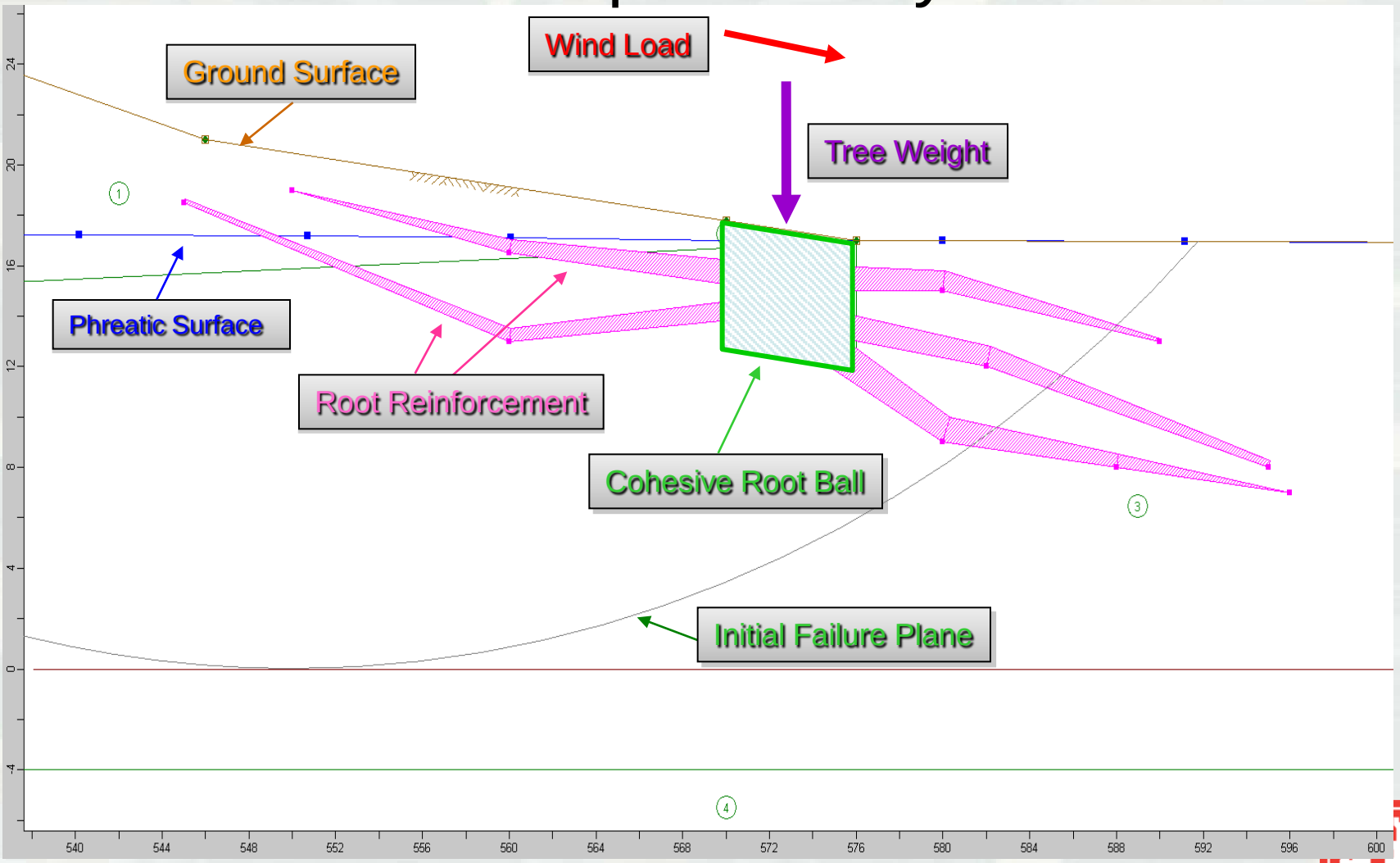




Pocket Levee, Sacramento, CA
Exit gradient from permeability variation
ERDC Veg Model Team 2010

Numerical Model Simulation

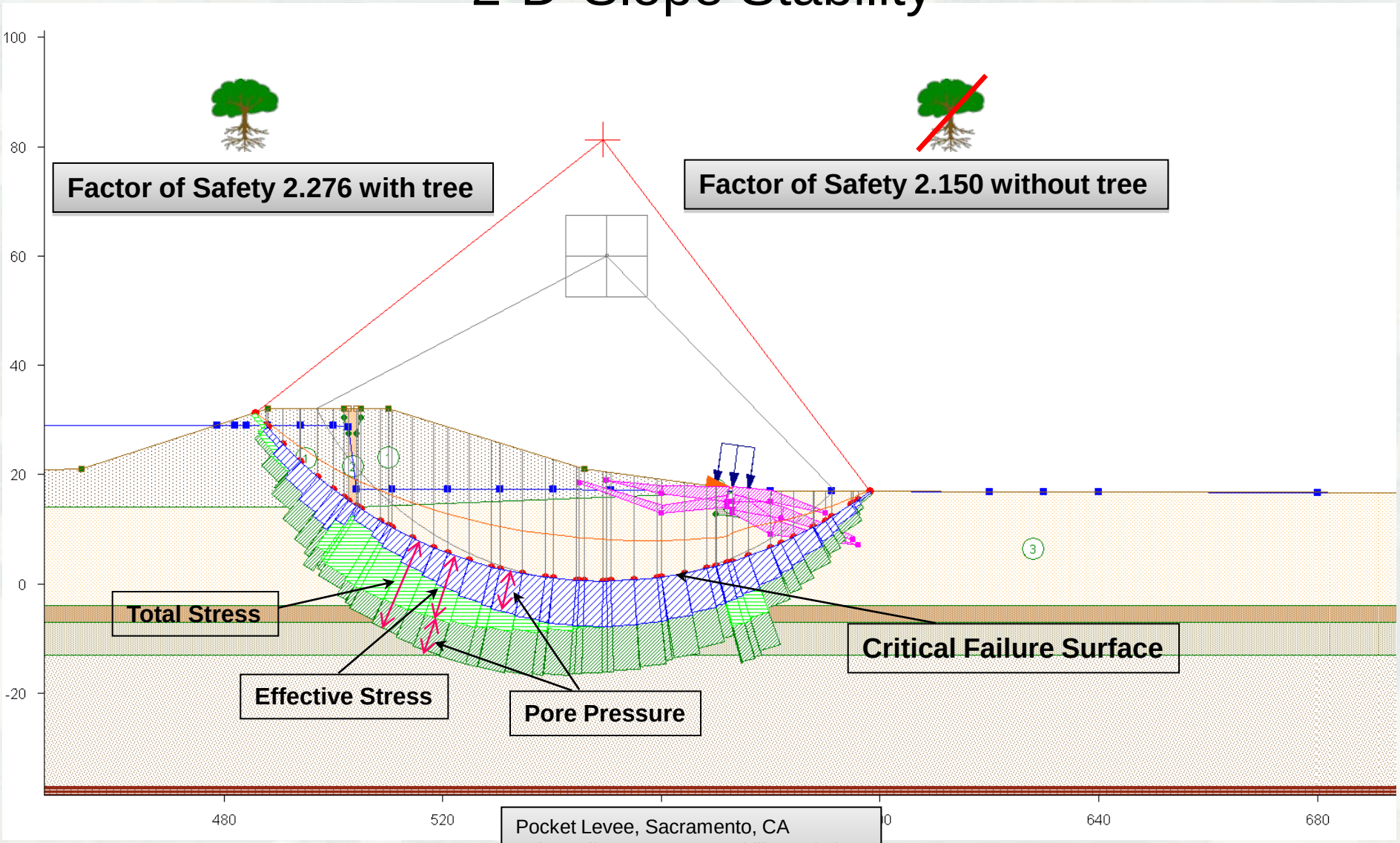
Slope Stability



Pocket Levee, Sacramento, CA
Slope stability input
ERDC Veg Model Team 2010

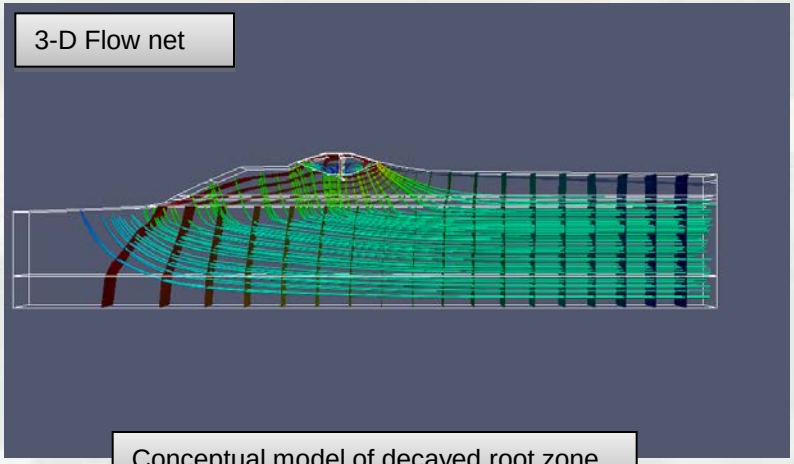
Numerical Model Simulation

2-D Slope Stability



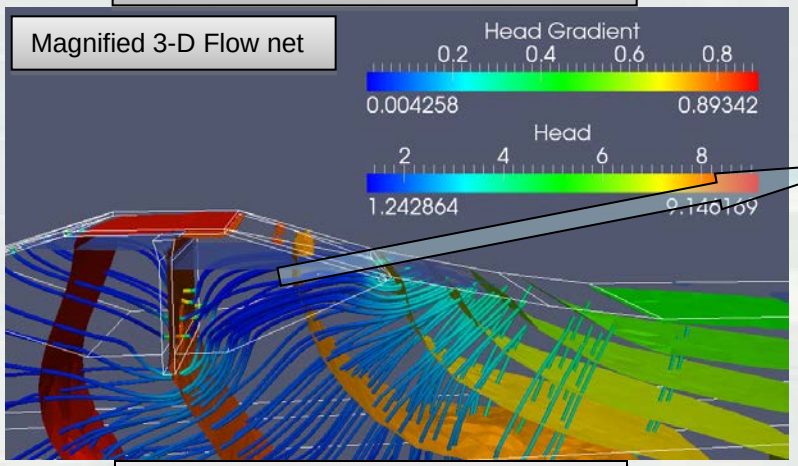
Pocket Levee, Sacramento, CA
Exit gradient from permeability variation
ERDC Veg Model Team 2010

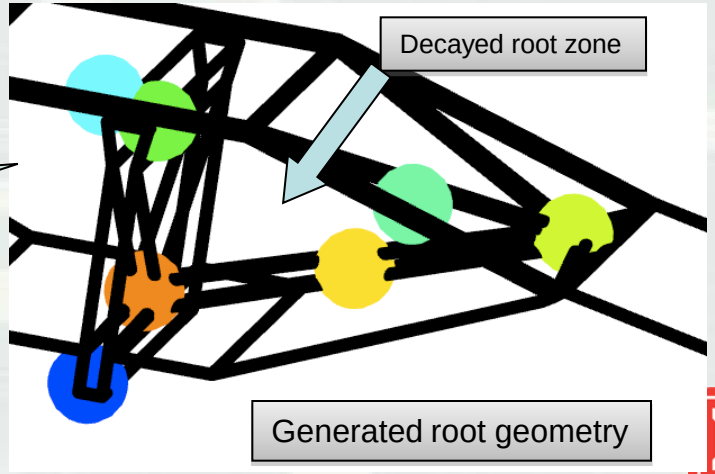
Numerical Model Simulation
3-D Seepage



Conceptual model of decayed root zone

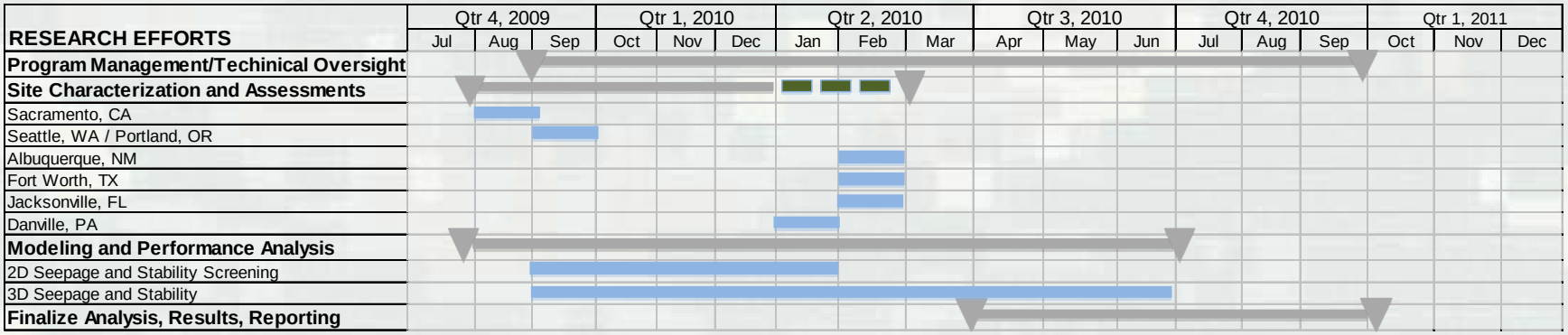
- ❑ Permeability increased in root at one order of magnitude higher than surrounding soil
- ❑ Significant seepage at levee toe
- ❑ High exit gradient at levee toe





Pocket Levee, Sacramento, CA
ERDC Veg Model Team 2010

Schedule


RESEARCH EFFORTS
Qtr 4, 2009
Qtr 1, 2010
Qtr 2, 2010
Qtr 3, 2010
Qtr 4, 2010
Qtr 1, 2011
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Program Management/Techinical Oversight
Site Characterization and Assessments
Sacramento, CA
Seattle, WA / Portland, OR
Albuquerque, NM
Fort Worth, TX
Jacksonville, FL
Danville, PA
Modeling and Performance Analysis
2D Seepage and Stability Screening
3D Seepage and Stability
Finalize Analysis, Results, Reporting

Status Summary

- Field data collection and model analyses are on schedule
- Model screening
  - Seepage is complete
  - Slope stability will be completed by Mar 2010
- Model runs
  - 2-D and 3-D seepage (Sacramento 90%; Burlington 30%; Portland 10%) - Expected completion of all runs 15 Jun 2010
  - 2-D and 3-D slope stability (Sacramento 40%; Burlington 0%; Portland 0%)
  - Expect completion of all runs by 15 Jun 2010
- Successful collaboration continues with CA stakeholders (Winter Workshop Jan 2010)

General Approach – 2D and 3D seepage and slope stability analyses

- Select a representative site (input from Districts, local flood agencies
- Produce hydrographs of peak flow
- Construct cross sections based on District data and ERDC field investigations
- Assign soil properties
- Produce finite element mesh (FEM)

Location	Site Selection	Hydrographs	Cross-sections	Soil properties	FEM
Sacramento, CA	√	√	√	√	√
Burlington, WA	√		√	√	
Portland, OR	√				