National Flood Risk Management
Woody Vegetation on Levees

Pete Rabbon
Office of Homeland Security
HQ, U. S. Army Corps of Engineers

US Army Corps of Engineers
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Vegetation Policies - Key Points

- USACE current standards are based on best available information.
- For areas of uncertainty, USACE will err on the side of caution for life safety.
- USACE is open to new science and information.
- USACE will revise standards when new information will improve them.

Considerations for the Standard

- Vegetation as Obstruction
  - inspection
  - maintenance
  - repair
  - flood monitoring
  - flood fighting
  - emergency repair

- Vegetation as Direct Impact
  - tree overthrow
  - vegetation-induced scour
  - hydraulic channel capacity
  - internal erosion
  - soil permeability
  - piping
  - seepage
  - slope stability
  - soil density

Key Concerns

Inspections and Maintenance

Floodfighting

Root Penetration

Overturning

Options

Policy Document	Policy Elements
System-Wide Improvement Framework (SWIF)	•Worst-first •Interim Progress Milestones •Long-term Plan •Regional Solutioneering Teams
ETL 1110-2-571 Standards	•Set-back Levees •Planting Berms •National Solutioneering Team •Can be part of SWIF
Vegetation Variance Process (PGL)	•Environmental Considerations •Technical Review •Vegetation Management Plan •Can be included in the SWIF

Improve Levee System and/or Seek Other Solutions

Reduce Flood Risk

System-Wide Improvement Framework

- Policy issued Nov 29, 2011
- Sponsors maintain eligibility for rehabilitation assistance while improving levee systems
- Incorporates "worst first“ to optimize risk reduction
- Encourages intergovernmental collaboration
- Provides time to address both levee safety and environmental and Tribal considerations
- Recognizes regional differences
- Two phase process – Letter of Intent followed by SWIF
- Ten letters of intent received, with four approved and six under review
- One SWIF Plan under review

Vegetation Variance Request Policy

- Levee vegetation standards are critical to levee integrity and life safety, and provide accessibility for inspections; operation and maintenance; and flood fighting.
- Permanent vegetation variance may be requested to meet unique, regional situations to preserve, protect, and/or enhance natural resources and/or protect rights of Tribal Nations.
- Safety, structural integrity, and functionality of the levee, and accessibility for inspection and flood fighting must be retained.

Draft PGL

- Ensure a consistent process for decision-making
- Provide up to 2 years to submit new variance (for existing variances)
- Clarified technical requirements
- Clarified USACE responsibilities
- Incorporated language to ensure coordination with resource agencies/tribes
- Clarified terms and overlap with SWIF

Draft PGL – Next Steps

- Second public comment period ended April 17, 2012.
- NMFS has requested further discussion on the approach to consultation.
- Delayed final policy until discussions with the resource agencies are complete.

Overview of Initial Research into the Effects of Woody Vegetation on Levees

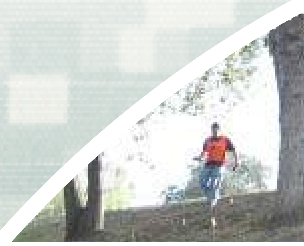
Maureen K. Corcoran, PhD, RPG
Associate Technical Director
Water Resources Infrastructure

U.S. Army Engineer Research and Development Center
Vicksburg, MS

Presentation to:

Ecosystem Restoration Webinar

18 Sept 2012



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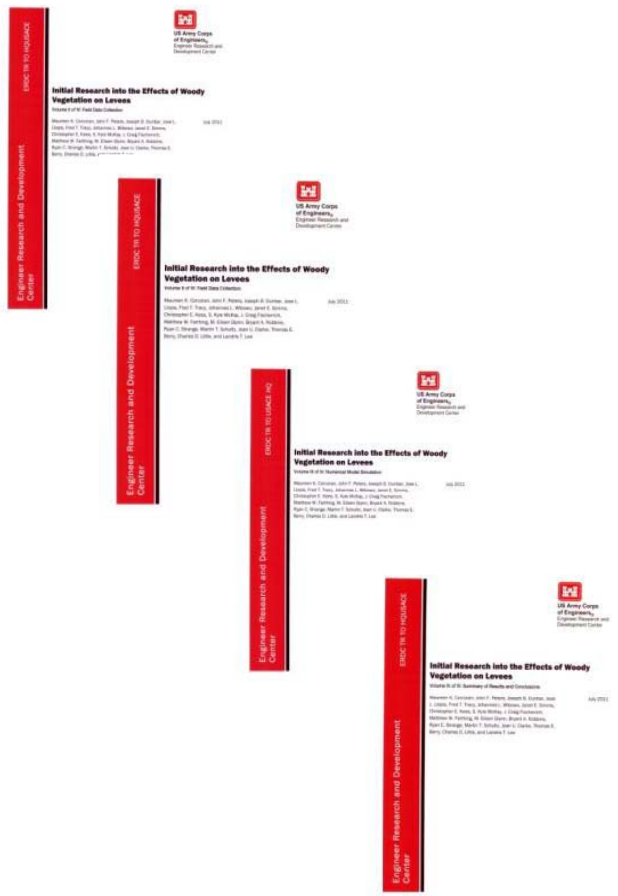
Background

- **June 2007 –** Headquarters, U.S. Army Corps of Engineers (HQUSACE) requested that the U.S. Army Engineer Research and Development Center (ERDC) perform a literature review of the effects of woody vegetation on the structural integrity of levees

- **Dec 2007 –** Literature review revealed that there are only a few publications directed toward the study of woody vegetation on levees

- **Sept 2009 –** Because of the limited research found in the literature review, ERDC begins initial research on two processes: seepage (initiation of internal erosion) and slope stability (simple, deep-seated failures)

- **Sept 2011 –** Technical report (four volumes, one appendix) released to public
  http://wri.usace.army.mil/



Data Gaps in Previous Research

- Soil mechanics usually assumed
- Tensile strength of roots for different species not well documented
  - Difficulty in obtaining tensile strength for each species
- Previous slope stability models did not account for root morphology, root topology, and root geometry
- Models for vegetation based on channel banks
- ALL aspects of levee vegetation not addressed in one research project

Effects of Woody Vegetation on Levees

Objective – Develop method to quantify the impact of woody vegetation on the structural performance of earthen levees using scientific and engineering tools

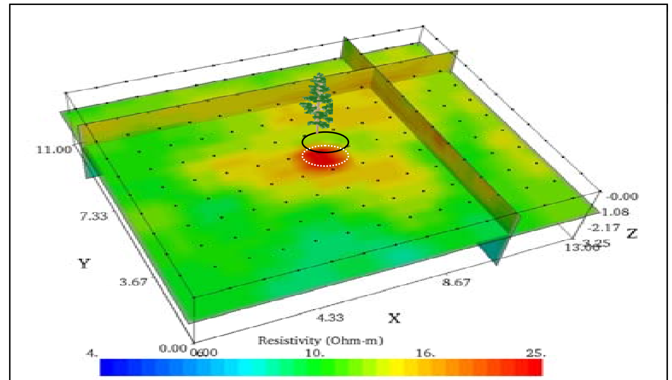
Approach

Task 1. Conduct extensive literature review

Task 2. Select study sites

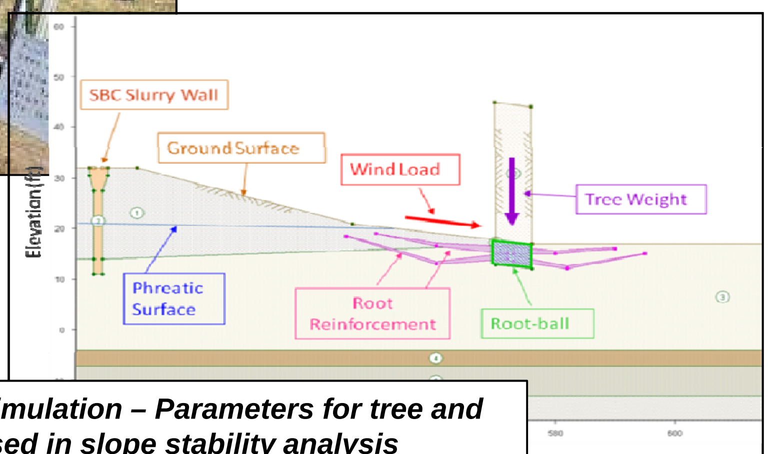
Task 3. Field data collection

Task 4. Numerical model simulation for processes involved in slope stability and seepage

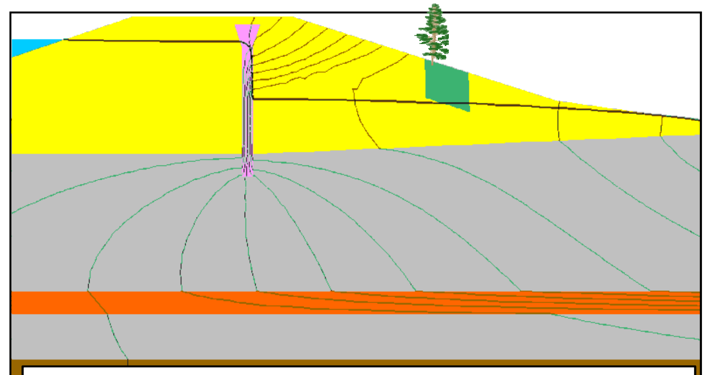


Field Data Collection –geophysical methods Used to define root zone for model input

Field Data Collection – root pullout device used to measure soil strength for model input



Numerical Model Simulation – Parameters for tree and levee interaction used in slope stability analysis



Numerical Model Simulation – 2-D seepage model showing the influence of a root zone on a flow field

Approach

- ❑ **Task 1- Conduct an extensive literature review**
  - Compilation of documents, government reports, international guidance, and journal articles concerning woody vegetation on levees
    http://wri.usace.army.mil/
- ❑ **Task 2- Select study sites**
  - Considered levee geometry, soils, geology, geographic setting, geotechnical reports, and tree species

Site Characterization
- ❑ Sacramento, CA
- ❑ Burlington, WA
- ❑ Portland, OR
- ❑ Albuquerque, NM

Site Assessments
- ❑ Danville, PA
- ❑ Boca Raton, FL
- ❑ New Orleans, LA
- ❑ Lake Providence, LA
- ❑ Lewisville, TX
- ❑ Vicksburg, MS

Examples of Woody Vegetation on Levees

Approach

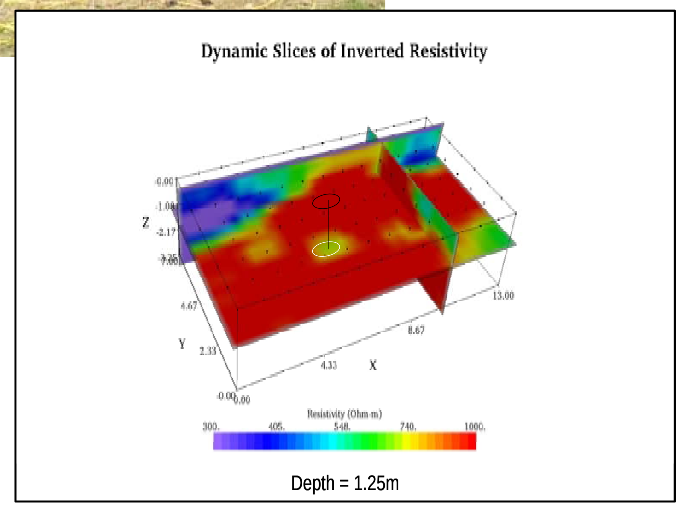
- **Task 3- Field Data Collection**
  - – Tool selection based on published research and consultation with experts in academia and private industry

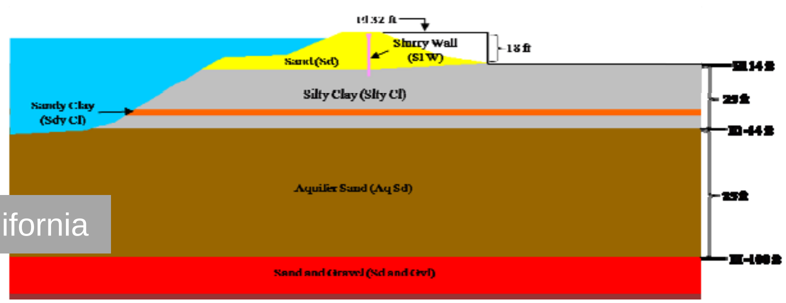
a. **Tree properties and identification**
   - Recorded tree species and their specific properties
   - Used existing literature to determine general root extent

b. **Root architecture**
   - Geophysical and in situ root mapping were used to define root system

c. **Root reinforcement for slope stability**
   - The strengthening effect of root systems were determined from a root pull-out apparatus that was applied in the field to measure tensile strength of roots

d. **Soil properties**
   - Existing geotechnical reports contributed to representative cross sections
   - Field tests were used to collect in situ hydraulic conductivity





Pocket Levee, California

Task 3. Field Data Collection

a. Tree Properties and Identification

Purpose – Trees and their properties were recorded both from the field and existing literature for slope stability and seepage model input

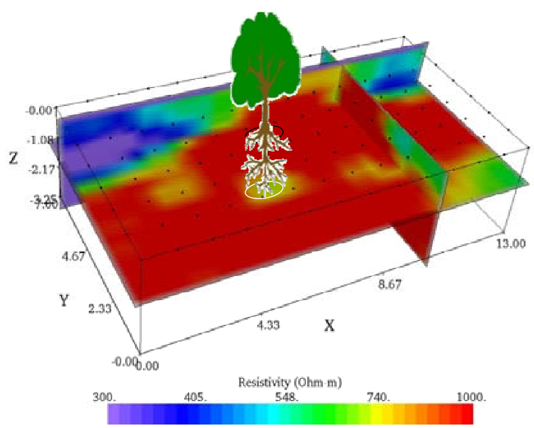
Common Name	Scientific Name	Location	Height (ft)	Root Depth (in)
Oregon ash	*Fraxinus latifolia*	Portland, OR	35	24
Cedar	*Thuja plicata*	Burlington, WA	40	30
Valley oak	*Quercus lobata*	Sacramento, CA	35	42
Alder	*Alnus rubra*	Burlington, WA	50	25

Task 3. Field Data Collection

b. Root Architecture – Geophysical

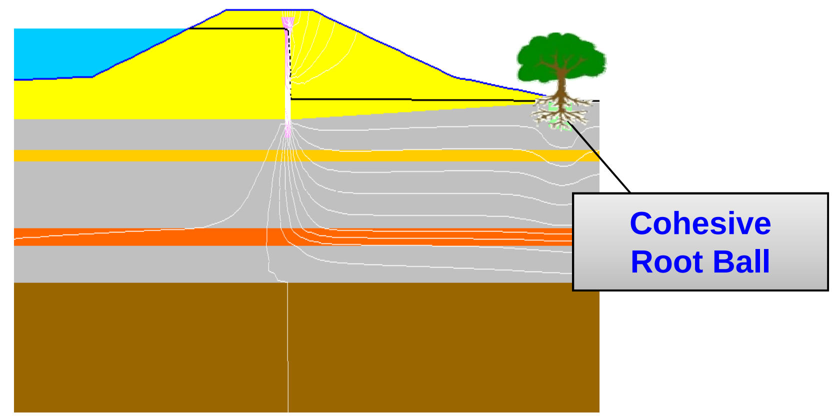
Purpose – to better understand the interaction of roots within the soil regime and the subsequent effect on the levee profile

❑ Defined cohesive root ball for input into seepage and slope stability models



Depth = 1.25m

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

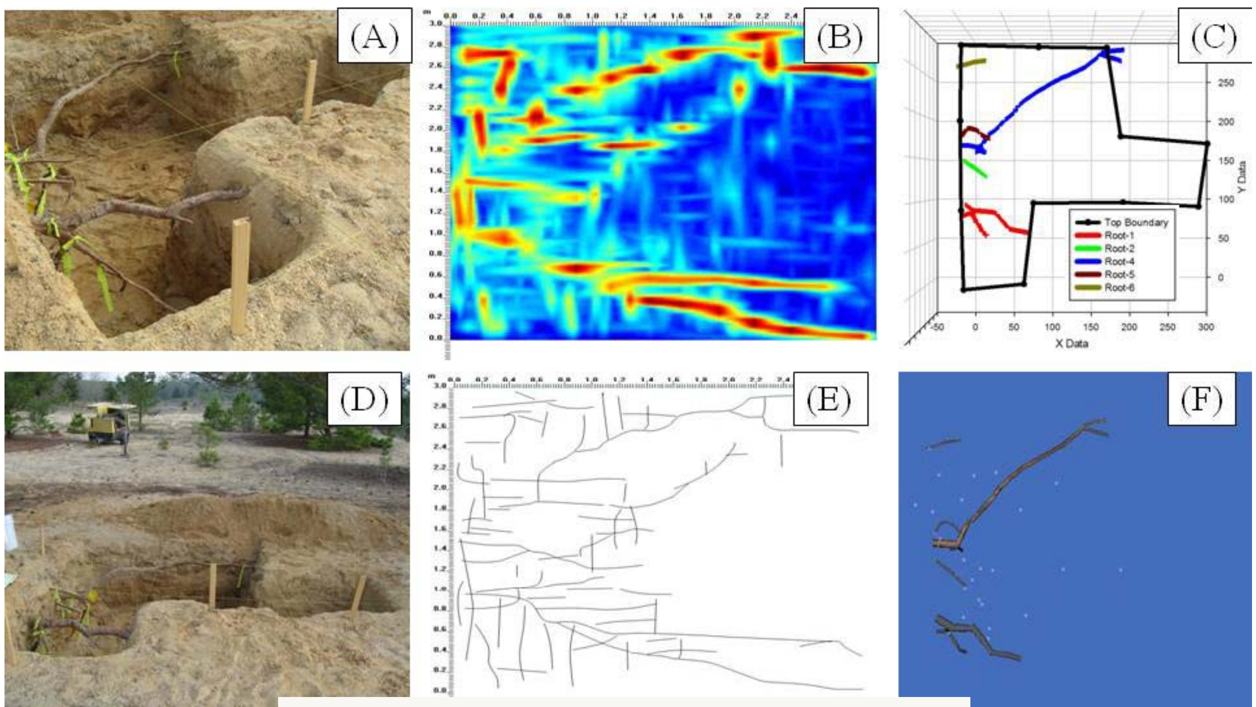


Pocket Levee, Sacramento, CA
Seepage analysis
ERDC Veg Model Team, 2010

Task 3. Field Data Collection

b. Root Architecture – In Situ Root Mapping

Purpose – to better understand the interaction of roots within the soil regime and the subsequent effect on the levee profile

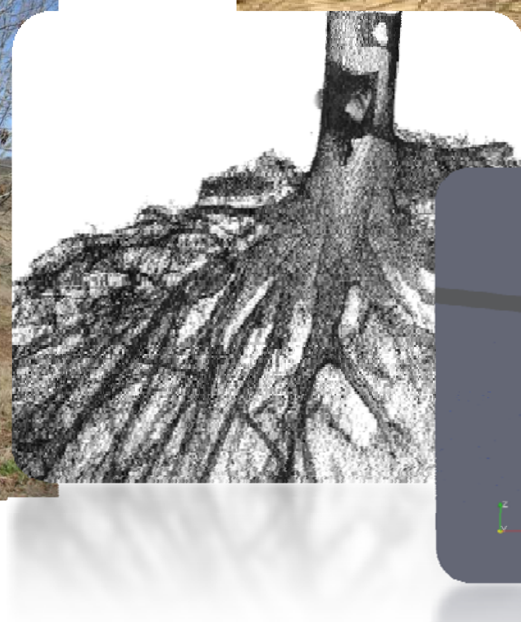


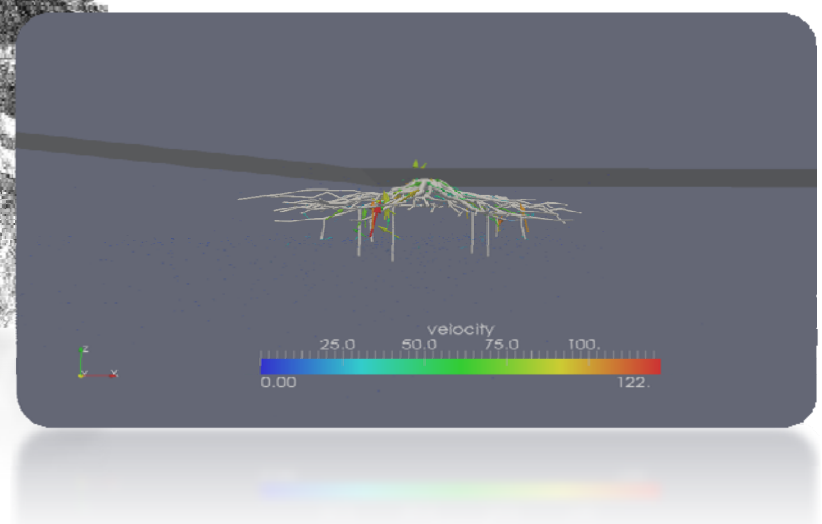
(A,D): Photographs of tree roots
(B): Ground penetrating radar
(C): Electromagnetic digitization
(E): Interpreted roots
(F): Calibrated photographic modeling

Task 3. Field Data Collection

<u>b. Root Architecture – In Situ Root Mapping (LiDAR)</u>

Purpose – to better understand the interaction of roots within the soil regime and the subsequent effect on the levee profile

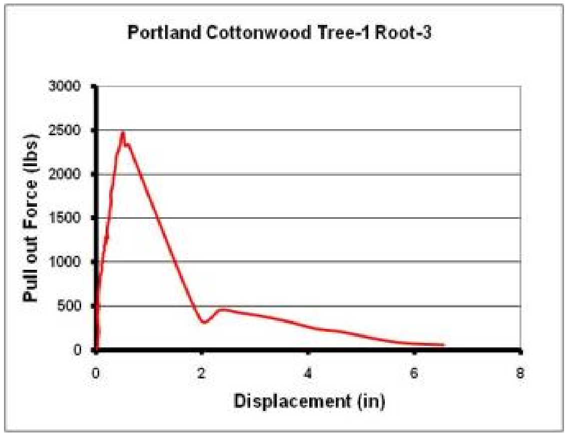




Task 3. Field Data Collection

c. Root Reinforcement for Slope Stability

Purpose – The strengthening effect of root systems was determined from a root pull-out apparatus that was applied in the field to measure tensile strength of roots



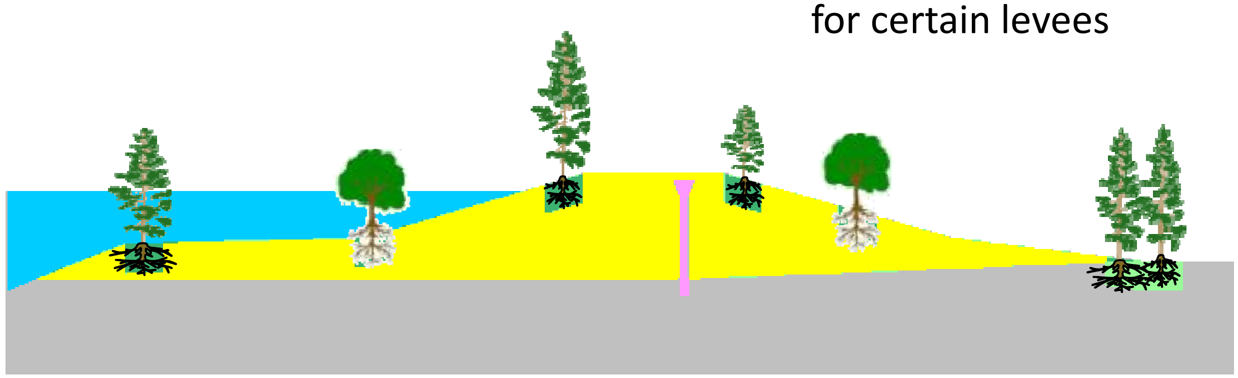
Root Length = 30 ft
Force = 3000 lbs
Force/Root Length = 100 lbs/ft

Slope Stability Model (UTEXAS4)

Task 4. Numerical Model Simulation

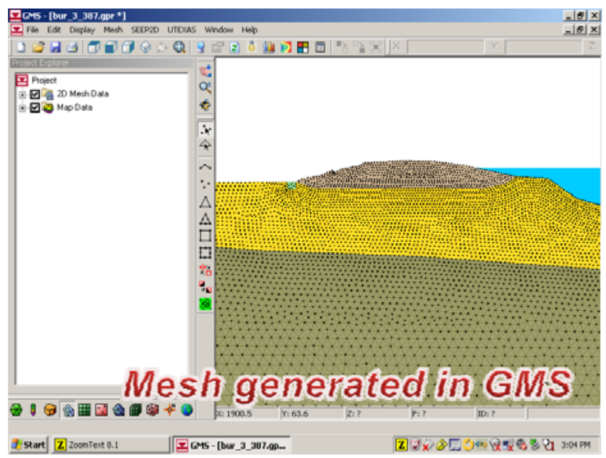
- Models are necessary to address variability
  - Soil properties
  - Root/soil interaction
  - Root system (difficult to categorize even among the same tree species)

- Analyses used both two-dimensional seepage and slope stability codes
- Representative levee cross sections and a relationship between factor of safety and flood level were established using specific geometry and soil profiles for certain levees



Primary Computational Tools

- ❑ Groundwater Modeling System (GMS)
- ❑ Seep2D
- ❑ UTEXAS4
- ❑ 3-D code developed for this project



Root Zone Model Types

- Changes in hydraulic conductivity
- Defect in a levee blanket
  - Assume simple defect
  - Embed an actual root shape into the root zone.
  - Conduct analysis using method described in, ***Internal erosion toolbox: A method for estimating probabilities of failure of embankment dams due to internal erosion (Schaefer, J.A. et al. 2010)***
- Macropore heterogeneity

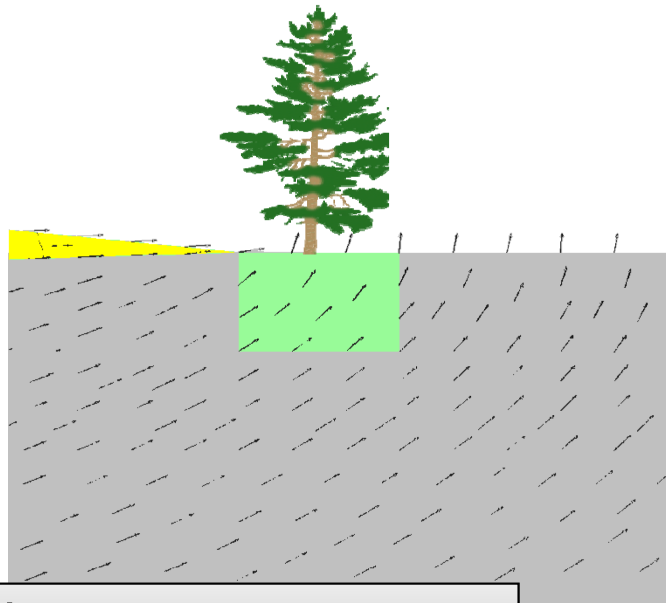
Task 4. Numerical Model Simulation

a. Modeling for Sensitivity Analysis

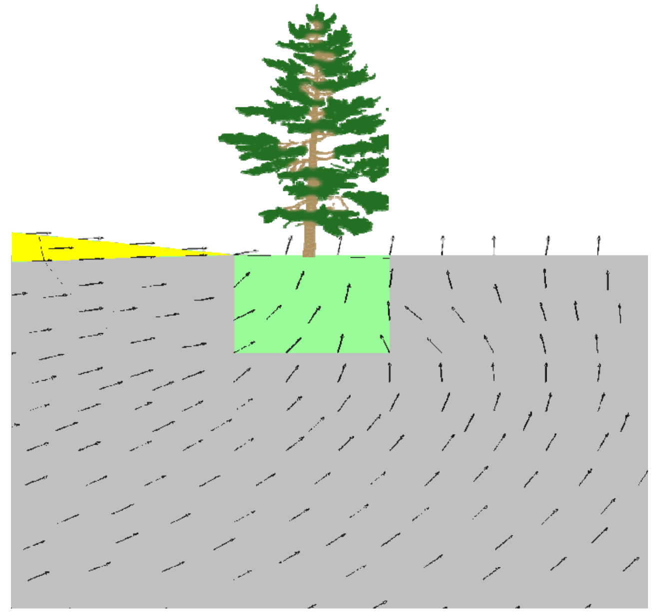
2-D Seepage

Purpose – explore the sensitivity of levee performance to changes in levee and vegetation parameters

$K_{vegetation\ zone} = K_{surrounding\ soil}$



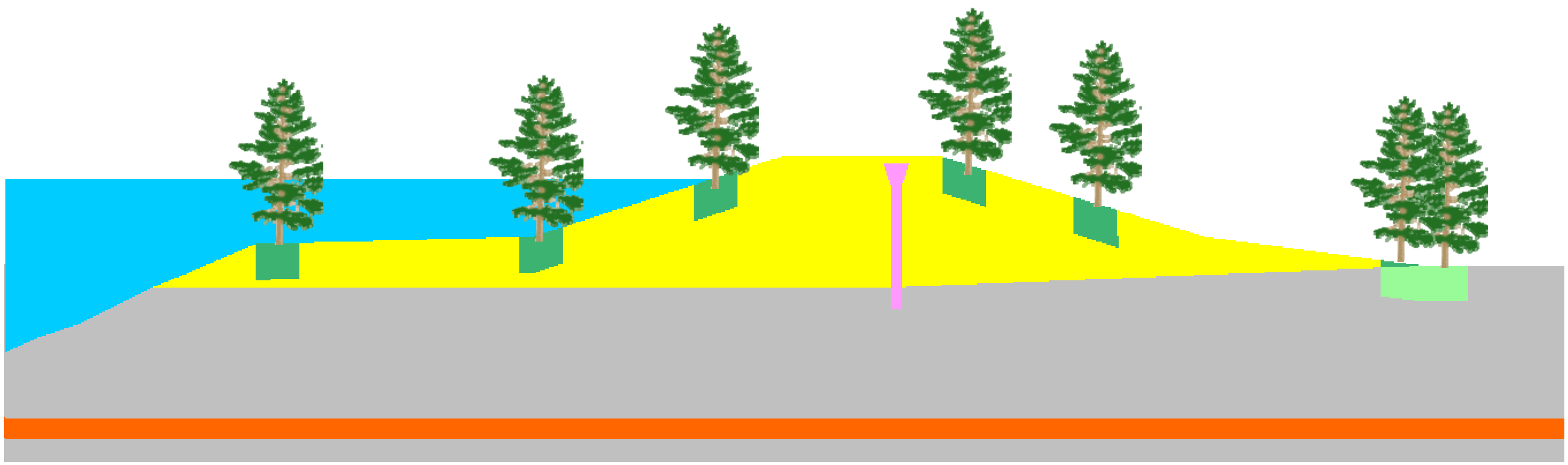
$K_{vegetation\ zone} = 10 \times K_{surrounding\ soil}$



Pocket Levee, Sacramento, CA
ERDC Veg Model Team 2010

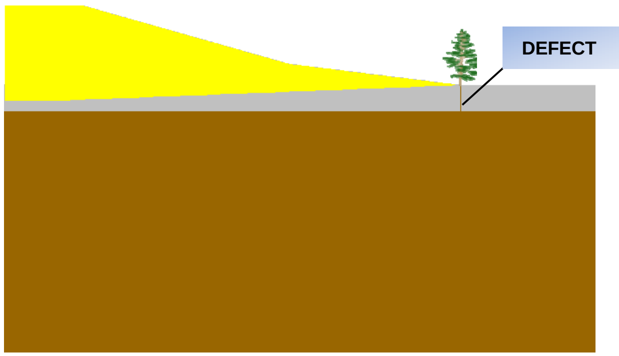
Hydraulic Conductivity Zone

$$k_{veg} = \beta\, k_{no-veg}$$

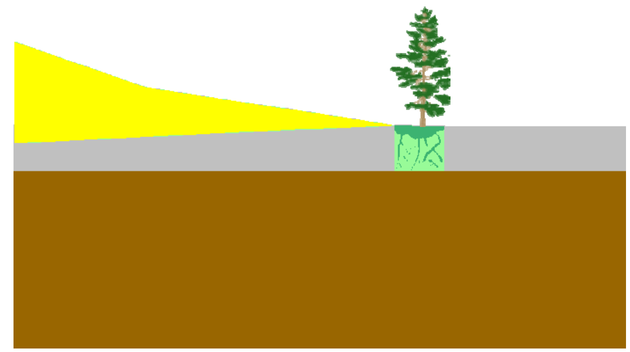


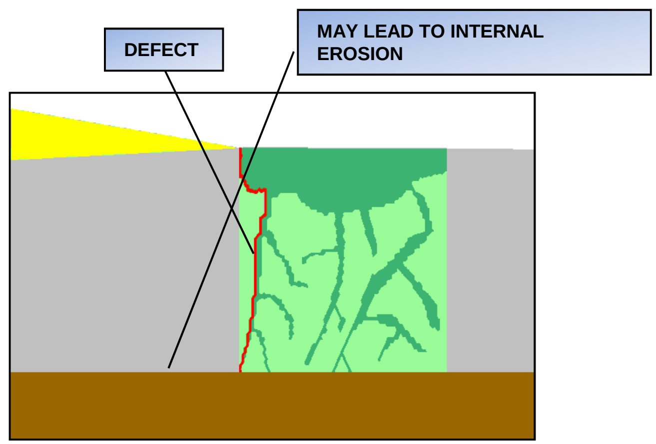
Seepage Analyses

Defect through confining layer

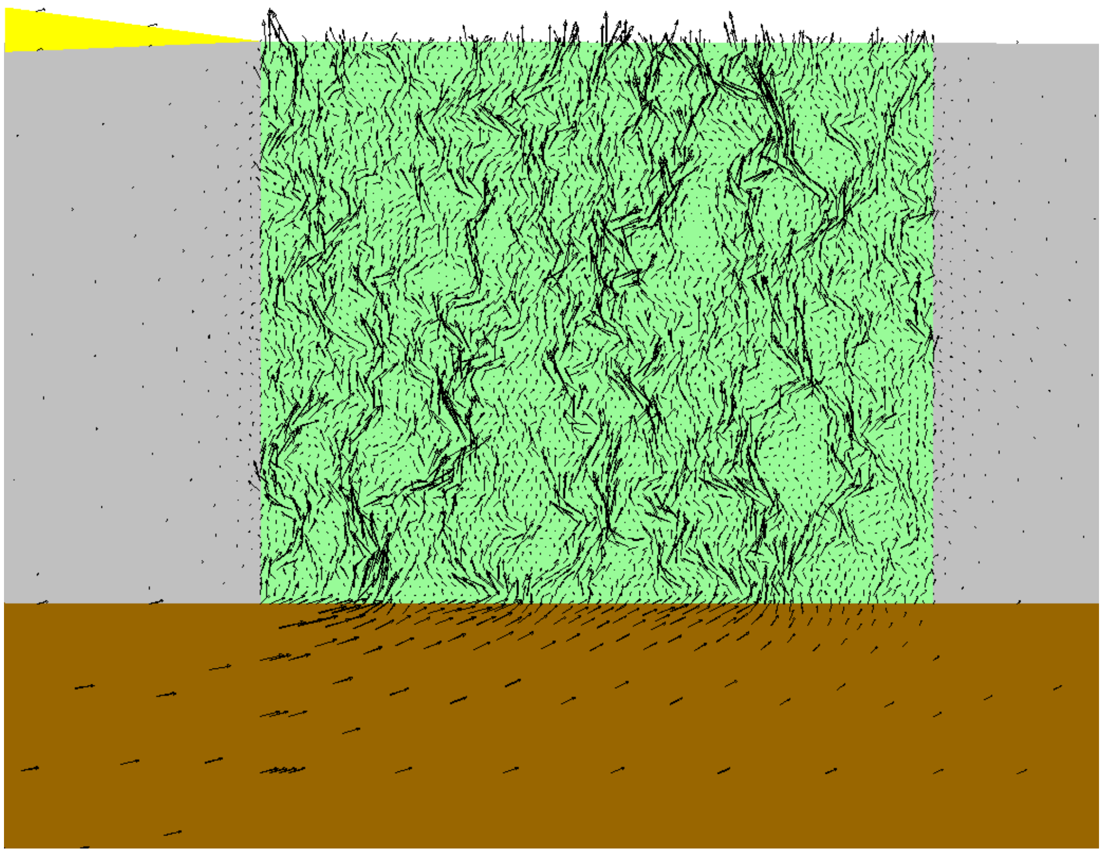


Defect from a root system



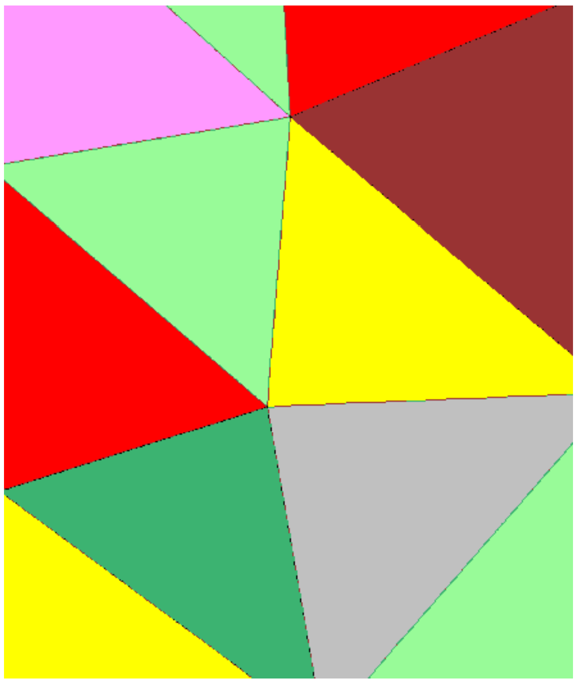


Macropore Heterogeneity
2-D Velocity Vectors



Macropore Heterogeneity

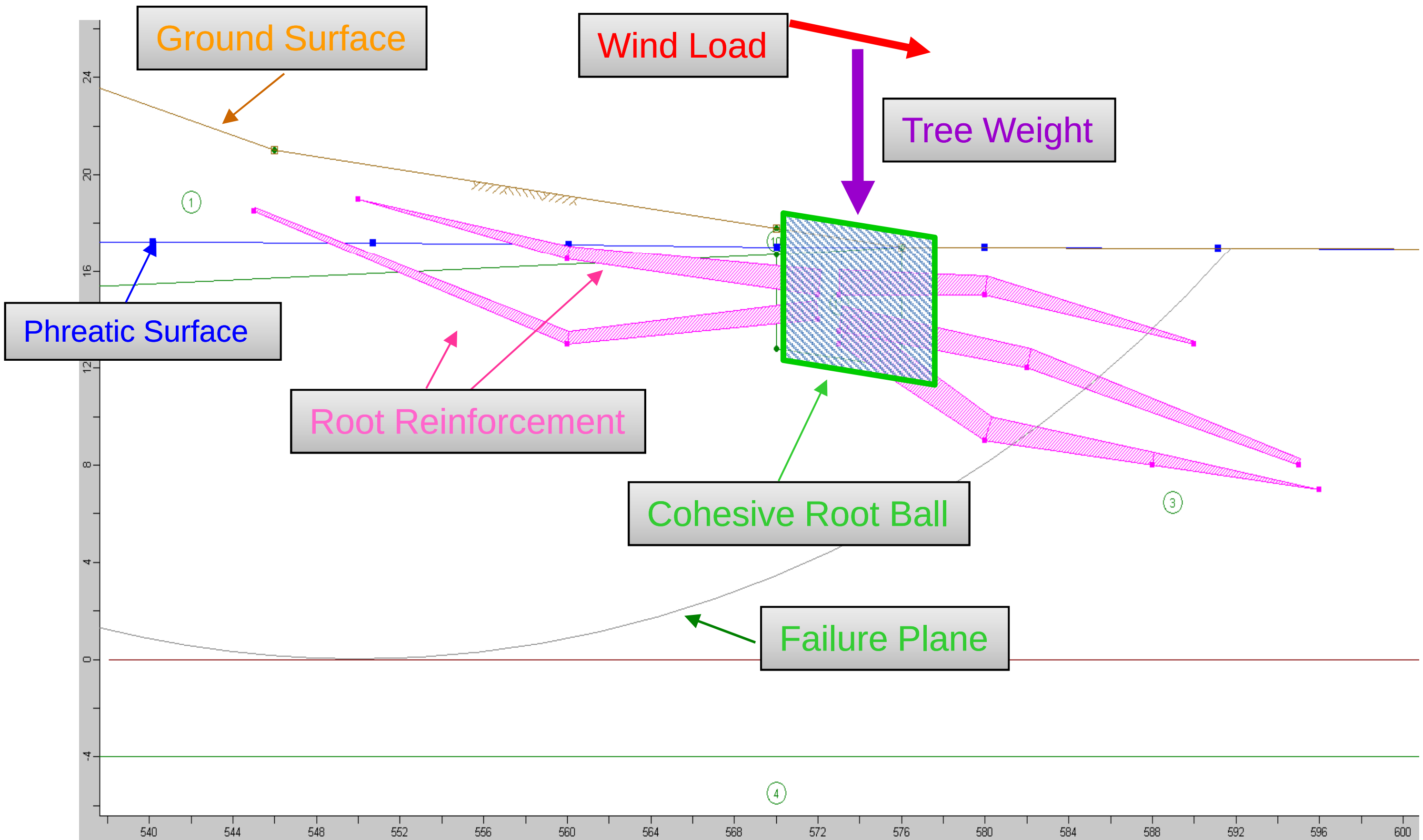
- Have a different β value that is randomly varied from 0.01 to 100 for each of the 1-inch elements.



$$k_{veg} = \beta\, k_{no-veg}$$

Task 4. Numerical Model Simulation

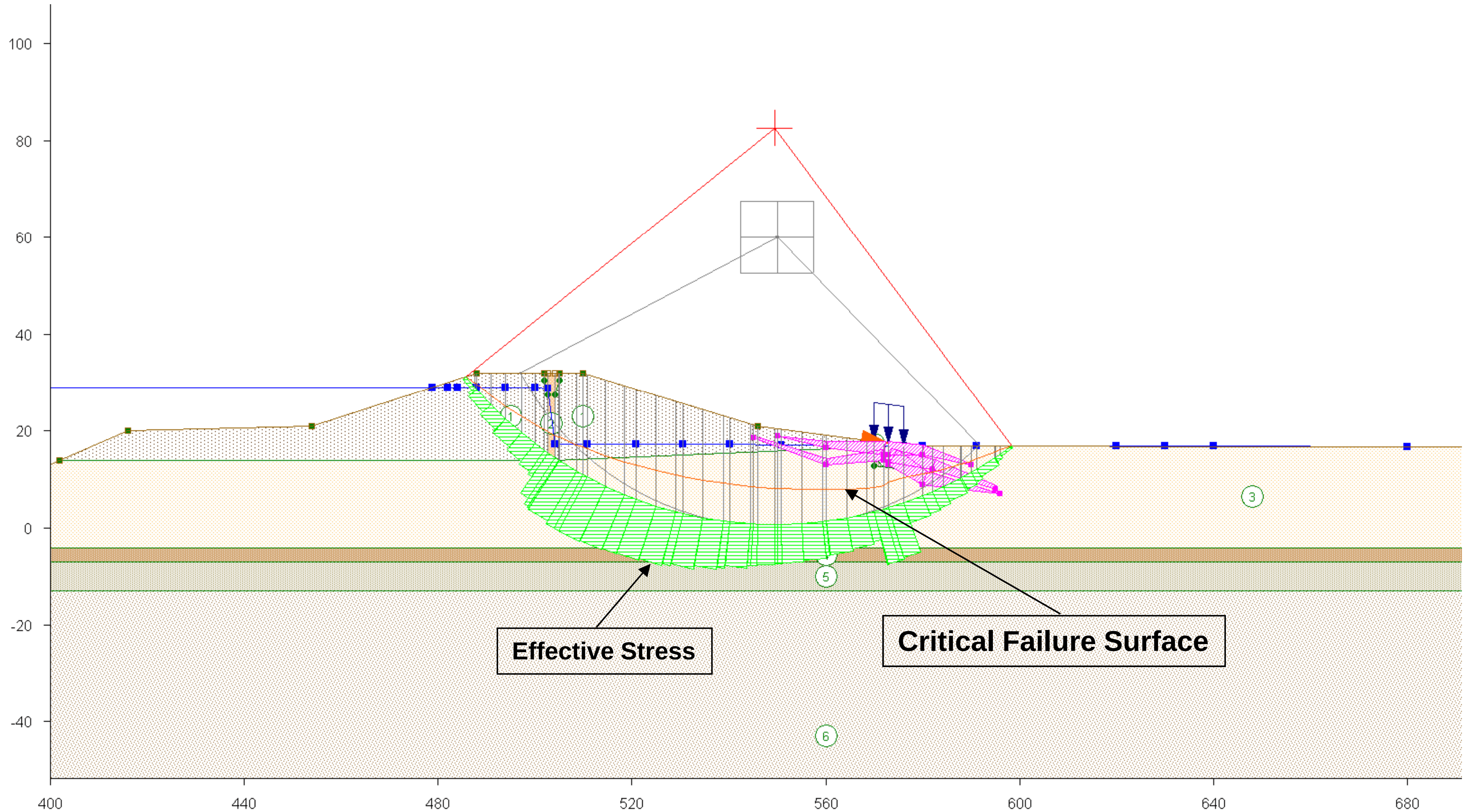
a. Modeling for Sensitivity Analysis



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

Task 4. Numerical Model Simulation

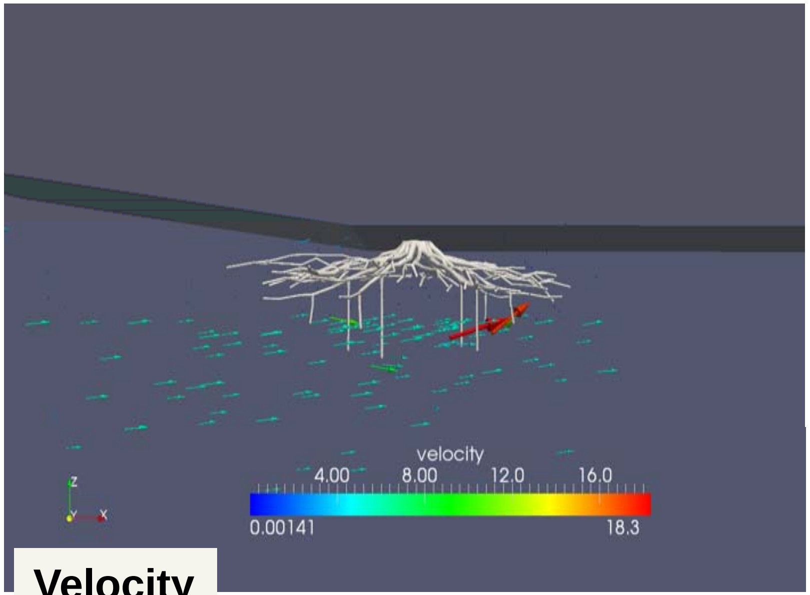
a. Modeling for Sensitivity Analysis



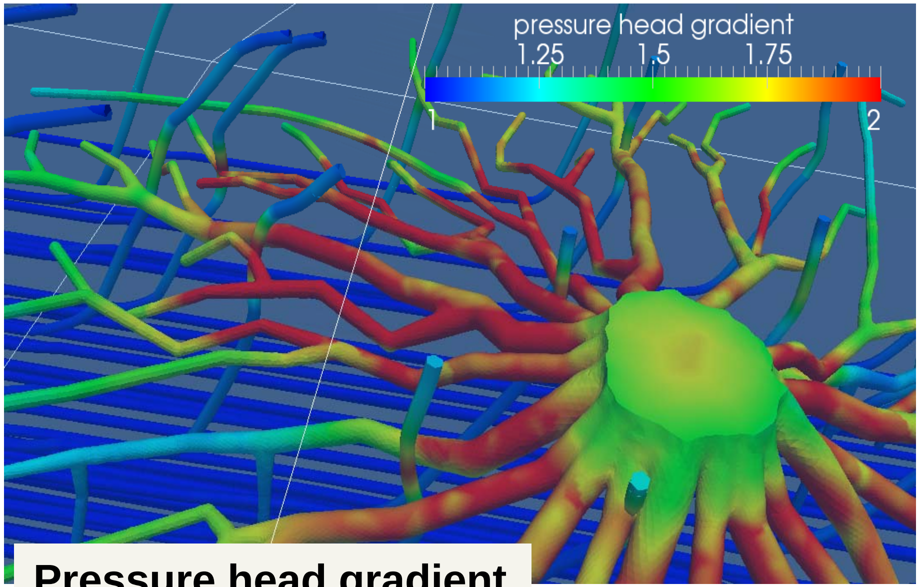
Task 4. Numerical Model Simulation

b. Deformation Analysis

Purpose – Improve understanding of tree root effects on levee performance



Velocity



Pressure head gradient

Product

- Technical report documenting methods used in quantifying the effects of woody vegetation on levee integrity and includes:
  - Approach developed and tested by ERDC from field data and geotechnical models at selected sites
  - Developed and modified root pullout device to record root strength
  - Developed three dimensional models for slope stability and seepage analyses

Research Questions

- What techniques are useful in identifying the spatial extent of root systems in situ?
- Are field methods successful in identifying in situ soil properties that may be affected by a root system and hence, affect levee performance?
- What are the parameters identified in the numerical models that may be sensitive to the presence of a root system?
- What variables are the most critical to the structural performance of the levee and the tree location and specific conditions that would most likely pose problems?
- The underlying question, “Does woody vegetation affect the levee structure?”

- *What techniques are useful in identifying the spatial extent of root systems in situ?*
  - Electrical resistivity imaging measurements proved useful in determining size and extent of tree root balls
  - Ground penetrating radar was effective in predicting location and orientation of individual roots

- Are field methods successful in identifying in situ soil properties that may be affected by a root system and hence, affect levee performance?
  - Hydraulic conductivity (k) measured around the root mass of a tree and compared to (k) measured around a control site without tree roots within the same reach of levee did not always correspond to the (k) used in the numerical models.

- *What are the parameters identified in the numerical models that may be sensitive to the presence of a root system?*
  - Major impact of the tree was its loading caused by its weight.
  - Root strength was not a critical parameter for deep-seated sliding.
  - Hydraulic conductivity had little to no impact on seepage flow paths or gradient

- *What variables are the most critical to the structural performance of the levee and the tree location and specific conditions that would most likely pose problems?*
  - Trees located on the slope above the phreatic surface had limited effect on seepage
  - Trees beyond the toe of the levee or at the de-watered drainage ditch made any appreciable difference to the value of the exit gradient
  - Trees in the upper part of the slope decreased the factor of safety because they add weight.
  - Trees near the toe increased the factor of safety because of the reinforcing effects of the roots and the increased counterweight effect of the tree to slope movement.
  - Trees at mid-slope have lesser effect on the factor of safety because they act as a load.
  - Factor of safety decreased when wind load was considered.
  - Strengthening effect of the roots to deep-seated failure modes is insignificant.

- The underlying question, “Does woody vegetation affect the levee structure?”
  - Complexity and variability associated with root systems, soil, geology, and levees make a single, definitive answer impossible with this research.
  - Reductions in the factor of safety reflect specific conditions.
  - If the flow field and pressure conditions are within the bounds of safety without woody vegetation, it will be equally safe if living, woody vegetation is present.
  - Factors, such as past performance of the levee and presence of sand boils, should also be considered.
  - Impact of trees on levees should be analyzed on a case-by-case basis.

Documentation of ERDC Research

- ***Initial Research into the Effects of Woody Vegetation on Levees***, released 8 Sep 2011, consists of four volumes:
  - Volume I of IV: Project Overview
  - Volume II of IV: Field Data Collection
  - Volume III of IV: Numerical Model Simulation
  - Volume IV of IV: Summary of Results and Conclusions
- Research report and literature review are available at http://wri.usace.army.mil/


Mississippi River
Mississippi River Levee
Flood stage 48 ft
River 59.31 ft
Expected 64 ft
Vidalia, LA
12 May 2011