Association of State Floodplain Managers

ARCADIS Design & Consultancy for natural and built assets

Risk Analysis of Vegetation on Levees

June 19, 2018

This is the story of . . .

Maintaining flood safety for people and infrastructure

Preserving a treasured community asset

Suiho-En, recognized as one of the 10 best Japanese Gardens in the Western Hemisphere

Donald C. Tillman Water Reclamation Plant

Located at the margin of the Sepulveda Flood Control Basin, Woodley Park, Van Nuys, CA


SUIHO-EN
NORTH
DCTWRP
WEST
FLOODWALL
EAST
BERM
SOUTH
BERM


WEST FLOODWALL

SOUTH BERM

EAST BERM

SOUTH BERM

WEST FLOODWALL

Background

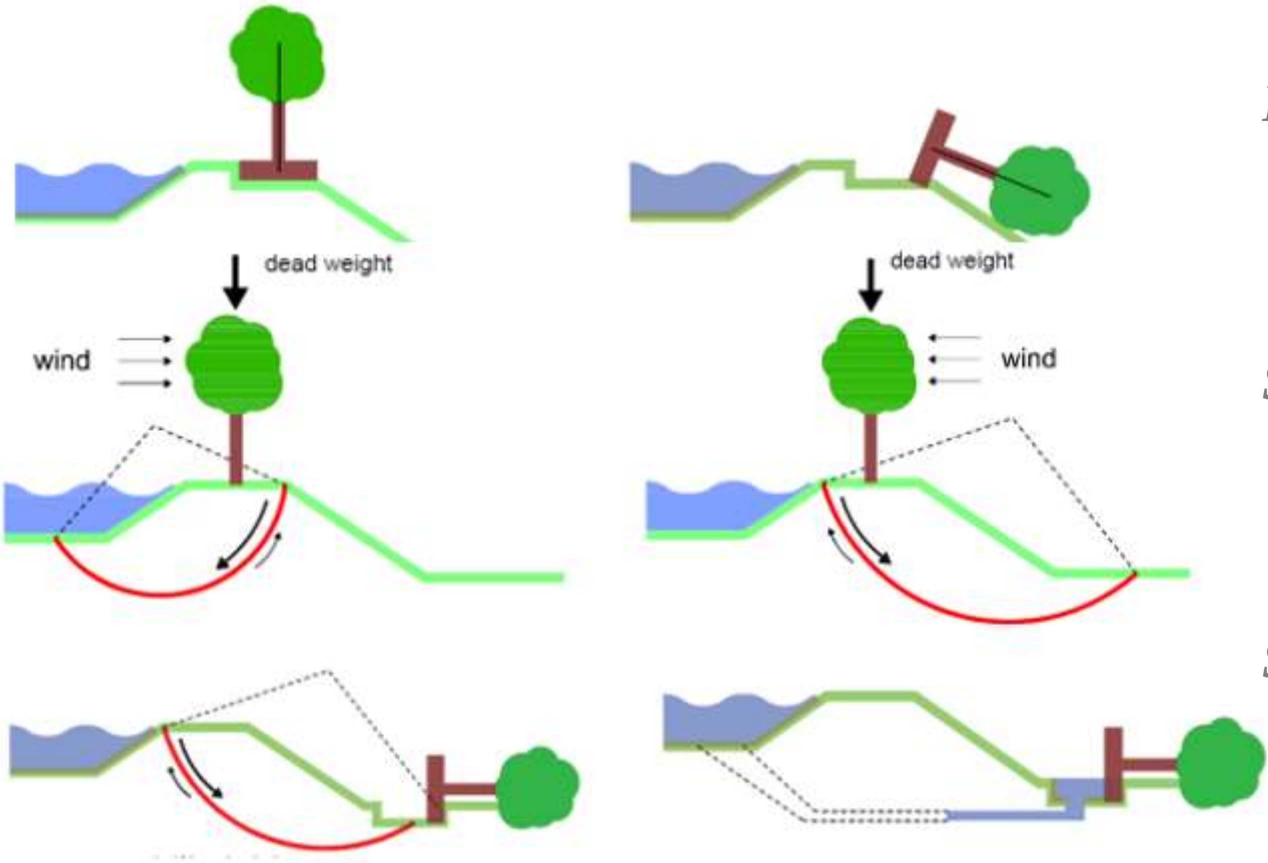
The DCWRP site is leased from the USACE

The lease expires in 2019, requires renewal

To renew the lease, the USACE requires

- Increasing the freeboard
- Adherence to its vegetation policy

Vegetation can pose threats to levees

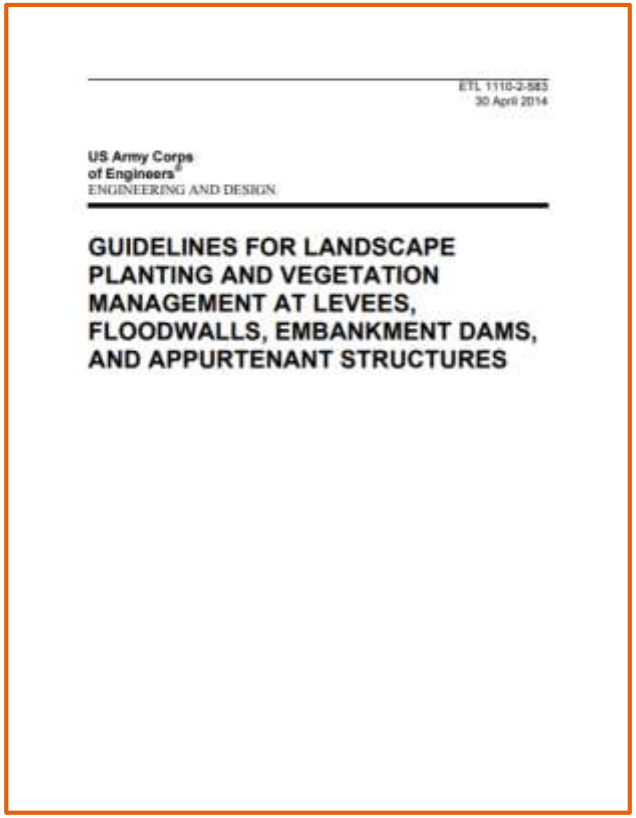


Reduced freeboard

Slope stability

Seepage paths

Excessive vegetation can hamper levee inspections and flood fighting



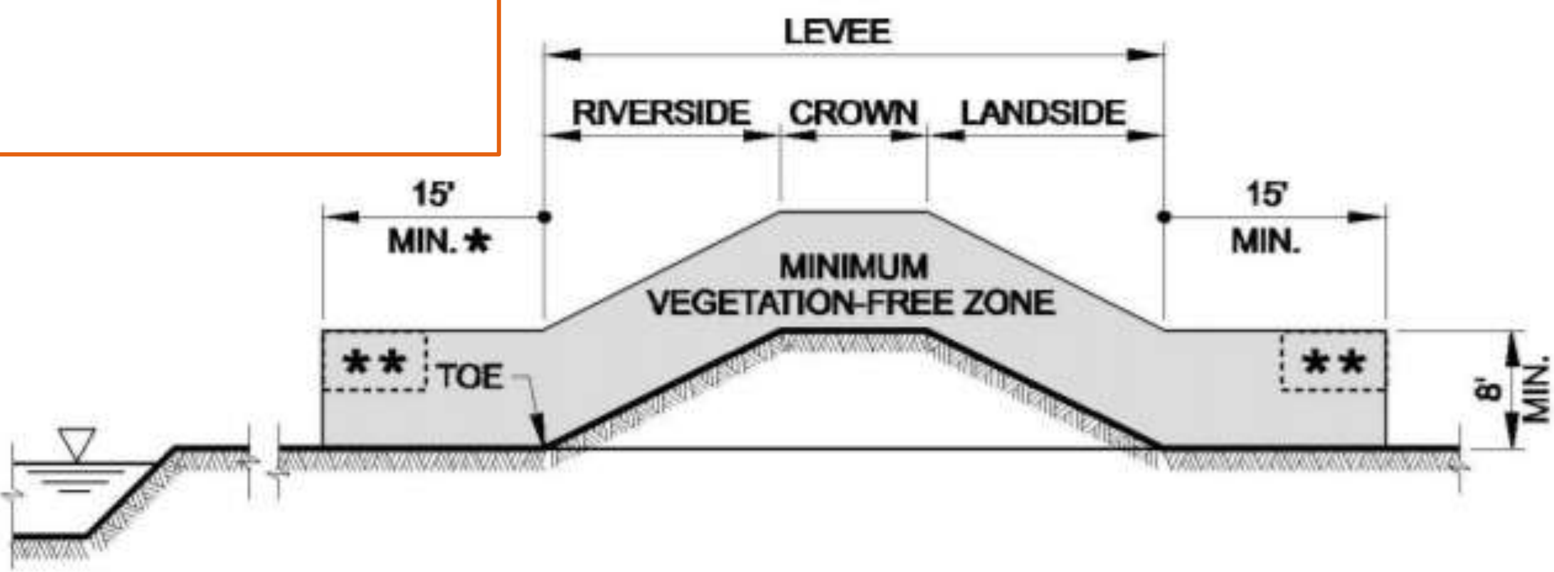
ETL 1110-2-583
30 April 2014

US Army Corps
of Engineers®
ENGINEERING AND DESIGN

GUIDELINES FOR LANDSCAPE PLANTING AND VEGETATION MANAGEMENT AT LEVEES, FLOODWALLS, EMBANKMENT DAMS, AND APPURTENANT STRUCTURES

Strict adherence to the policy would be:

- *Devastating to the aesthetics of Suiho-En*
- *Cost > $4-7 million*

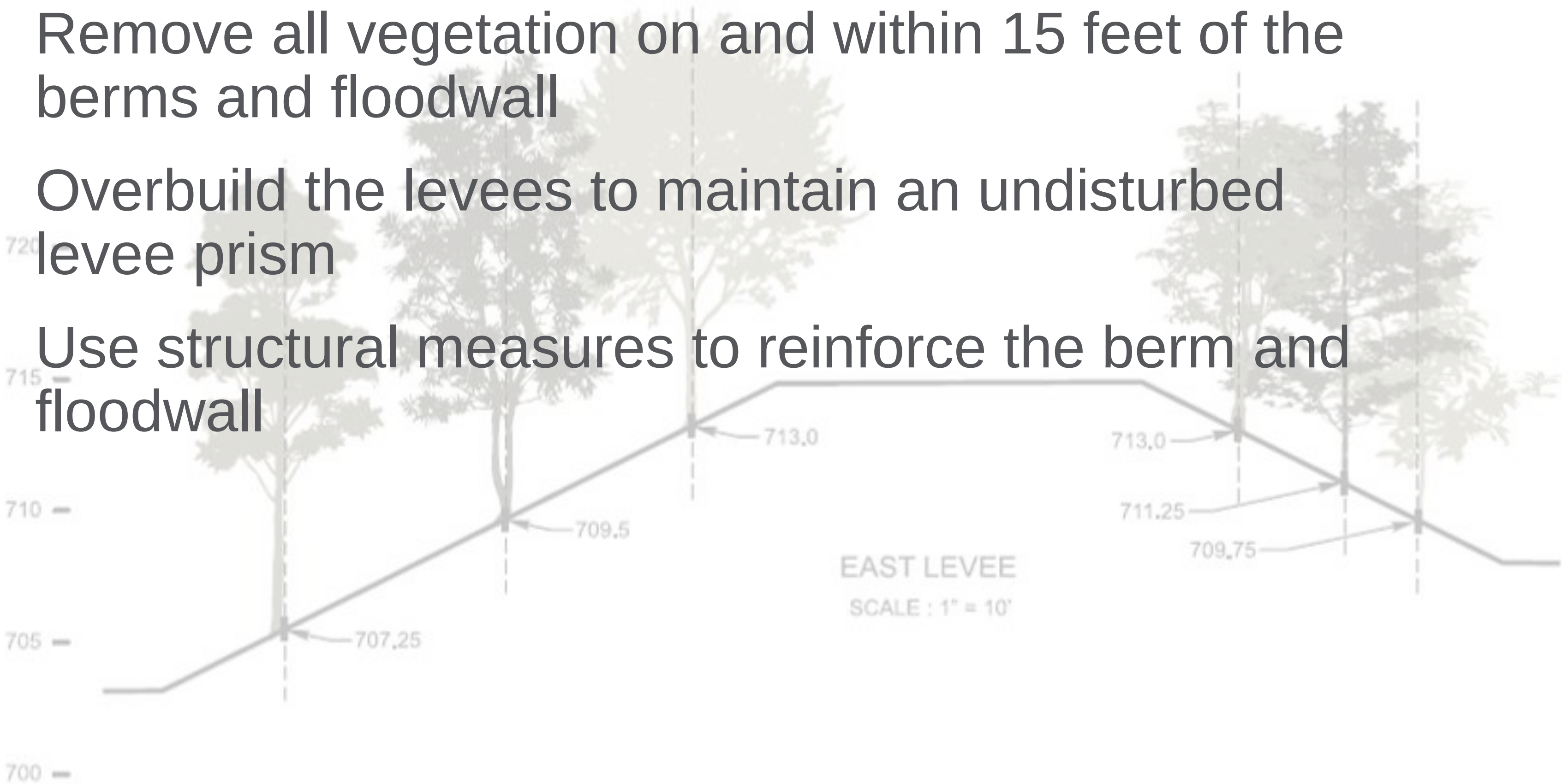


What to do?

Remove all vegetation on and within 15 feet of the berms and floodwall

Overbuild the levees to maintain an undisturbed levee prism

Use structural measures to reinforce the berm and floodwall



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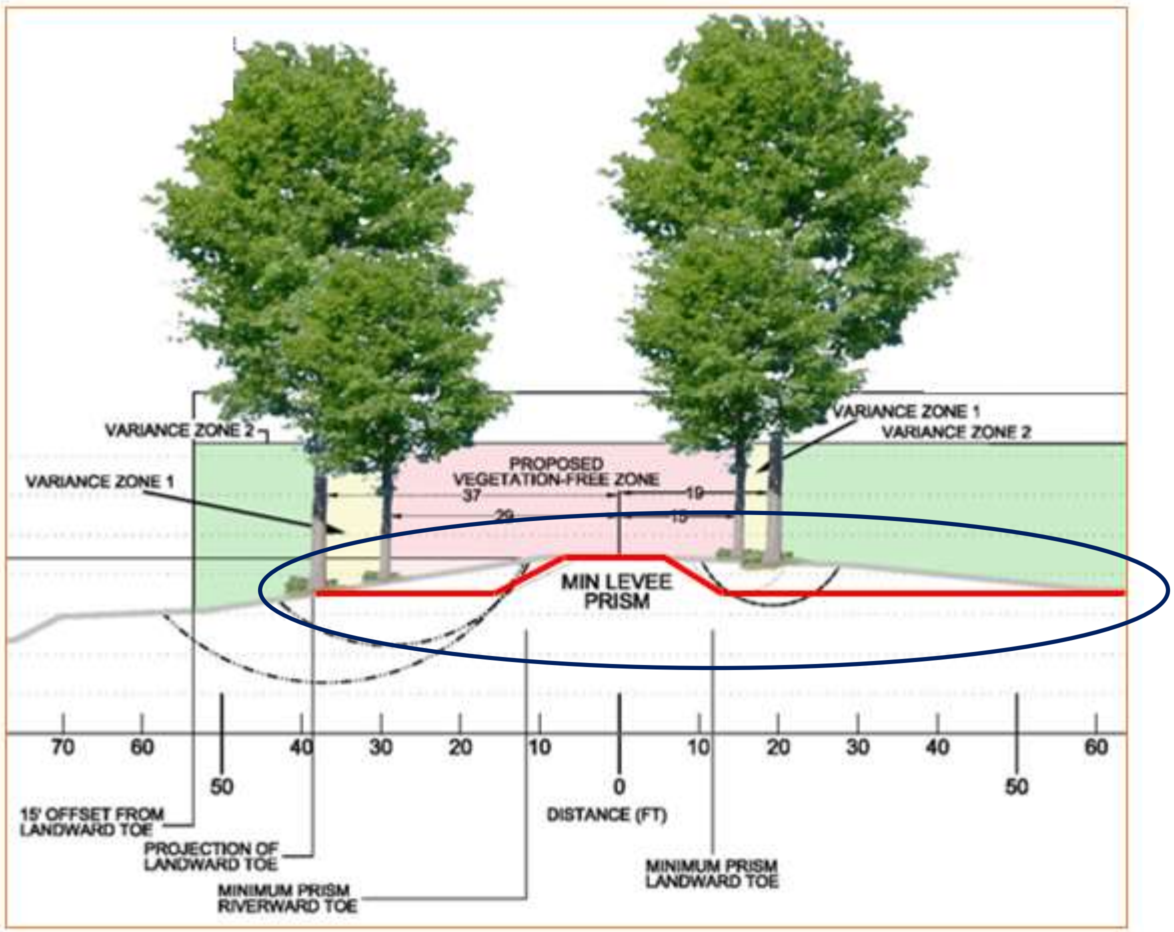
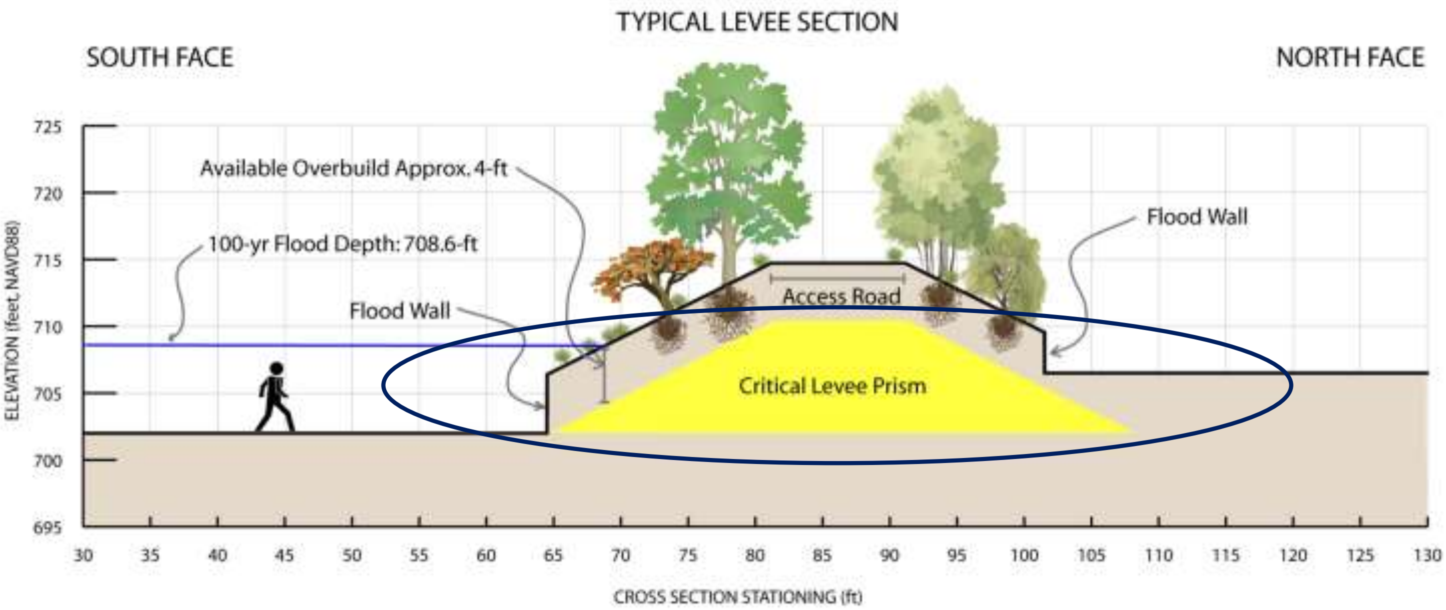
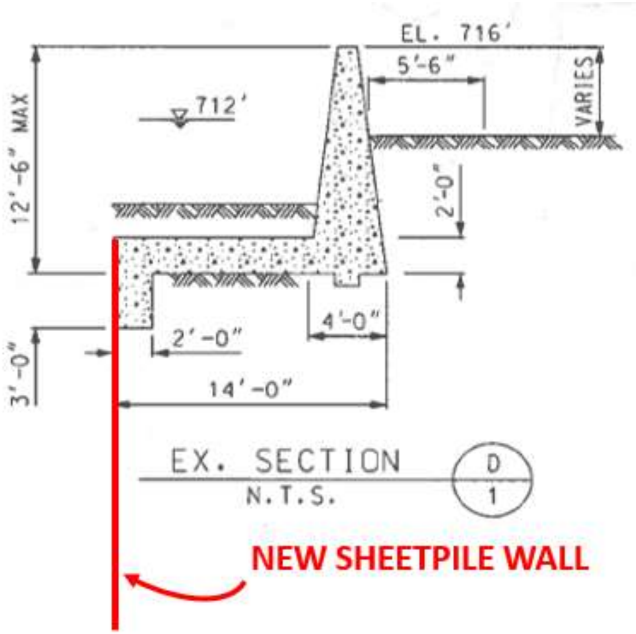


Maintain a minimum levee prism with vegetation outside the vegetation-free zone



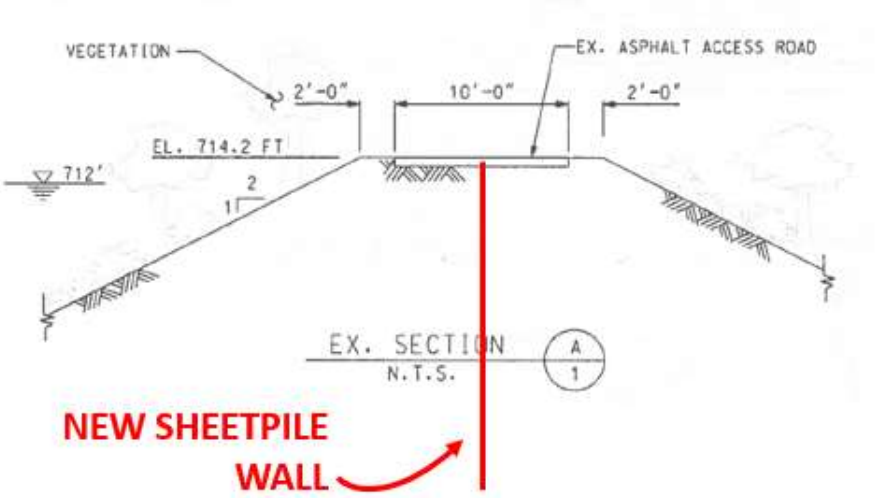
To accomplish this at DCTWRP

- Re-build levees with a 4-foot overbuild
- Use retaining walls to maintain lease boundaries
- Remove vegetation near the west floodwall


EL. 716'
5'-6"
VARIES
712'
12'-6" MAX
2'-0"
4'-0"
2'-0"
3'-0"
14'-0"
EX. SECTION
N.T.S.
D
1
NEW SHEETPILE WALL


NEW SHEETPILE
WALL


NEW SHEETPILE
WALL


VEGETATION
EX. ASPHALT ACCESS ROAD
2'-0"
10'-0"
2'-0"
EL. 714.2 FT
712'
2
1
EX. SECTION
N.T.S.
A
1
NEW SHEETPILE
WALL

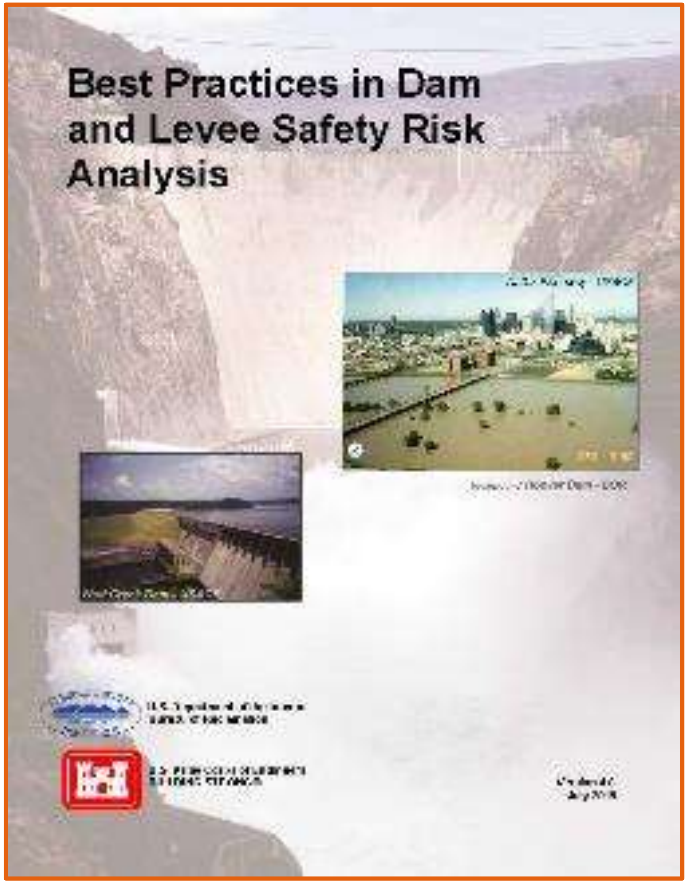
Analysis of alternatives

High cost and adverse public reaction was judged unacceptable

Maintaining the levee prism impractical due to space limitations and high cost

USACE rejected structural alternatives (e.g., sheetpiles)

USACE accepted risk analysis approach



USACE and USBR (2015)

1. Background	• *Collect and review*
2. Loading	• *What are the loads, the hazards?*
3. Consequences	• *What are the consequences of failure?*
4. Brainstorm	• *Identify Probable Failure Modes (PFMs)*
5. Risk Drivers	• *Discuss and evaluate*
6. Build Event Trees	• *Analyze each PFM*
7. Tolerable Risk	• *Is the risk tolerable?*

Risk analysis team

DCWRP

Three people from management

Three people from operations

One arborist from Suiho-En

Arcadis

Workshop leader (geotechnical engineer)

Arborist

Geotechnical engineer

Structural engineer

Three civil engineers

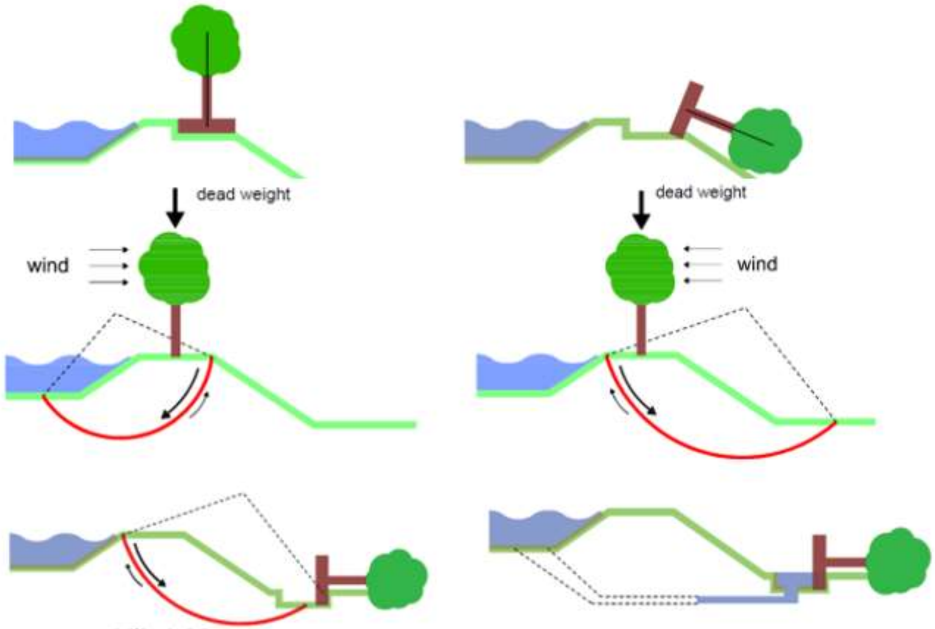
- WWTP designer
- PrecisionTree™ specialist
- Former Corps chief engineer

What is risk?

Common definitions of *risk*

- The possibility that something bad will happen
- Threats that can be identified, evaluated, and mitigated

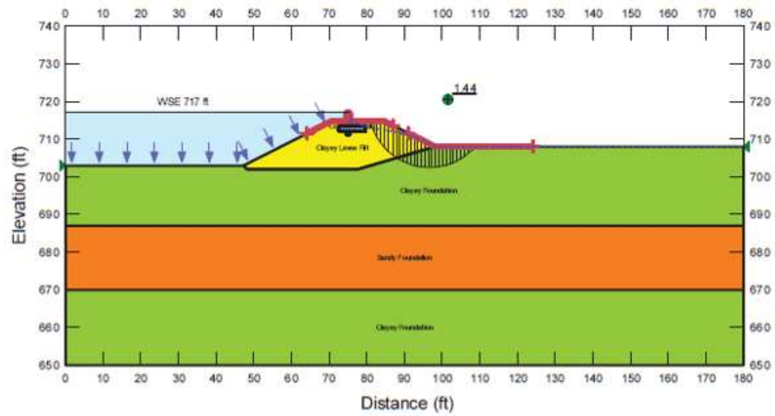
Risk = probability x consequences



Does the presence of trees materially increase the risk from flooding at the DCTWRP?

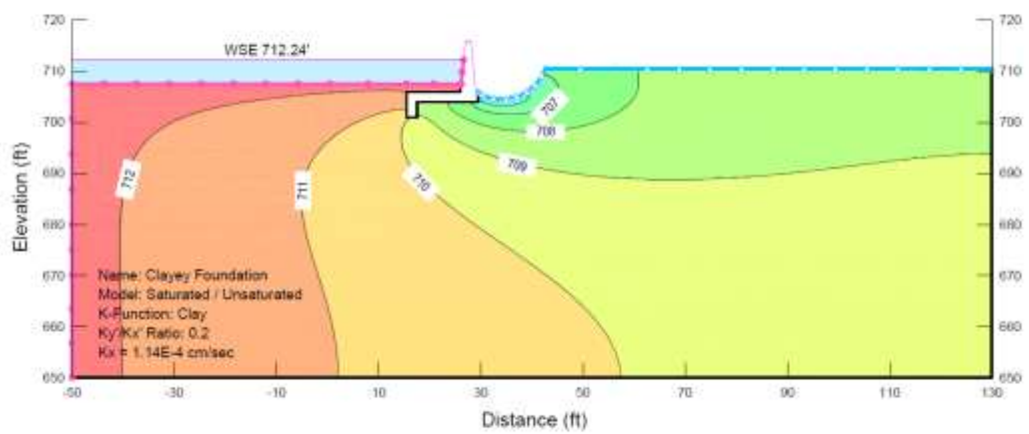
A wealth of background information

Extensive soil exploration and laboratory testing



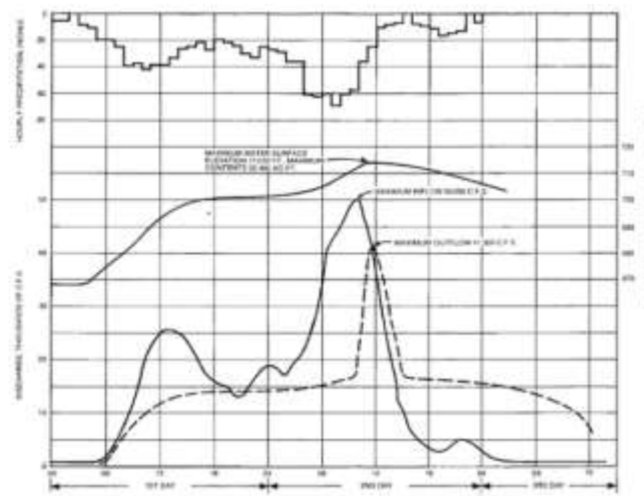
Slope stability analyses

Steady-state and transient seepage analyses



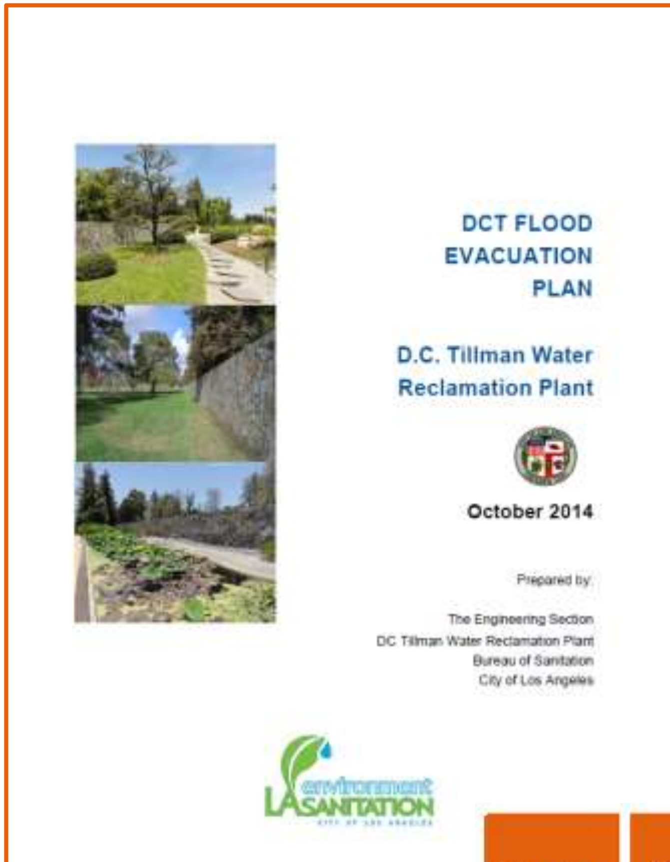
Probability of Reservoir Flooding

Percent Chance Exceedance	Return Period (years)	Basin Stage (ft, NGVD29)
0.2	500	714.6
0.5	200	713.5
1.0	100	712.0
2.0	50	705.0
5.0	20	699.5
10.0	10	697.7
20.0	5	692.5
50.0	2	687.4



Probability of High Winds

Case	Wind Speed	Probability (percent)
Low Wind	< 30 mph	20.0
Medium Wind	30 – 50 mph	55.4
High Wind	50 – 70 mph	19.8
Severe Wind	> 70 mph	4.8



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Potential consequences:

- *Loss of life*
- *Environmental damages from release of untreated wastewater*
- *Cost of cleanup and repair = $52 million*

Warning Level	Water Level in Reservoir	Population at Risk		Emergency Action
		DCTWRP Onsite Staff	Visitors and Contractors	
1	680<W.L.<688	80	<200	Evacuate public, contractors, and non-essential personnel
2	W.L.>700	<80	<10	Evacuate majority of staff and vehicles
3	W.L.>710	3	Negligible	Remaining staff (~3 people) move to administration building
4	W.L.>715	3	Negligible	Remaining staff shelters in place on 2nd floor of the administration building

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PFM	Description
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2	Oak on protected side topples, creates seepage path
3	Oak on flood side topples, creates seepage path
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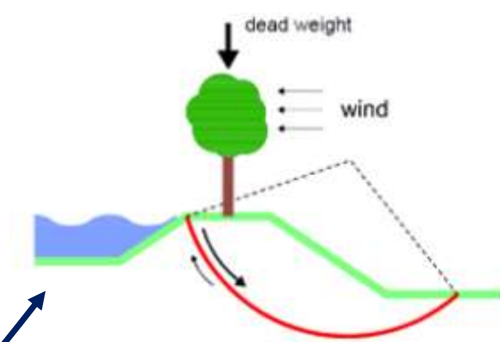
9	Erosion causes slope instability
10	Oak topples, damages floodwall
11	Oak on crest topples, creates seepage path
12	Oak on crest topples, creates slope instability

Probable failure modes

Examples of PFMs

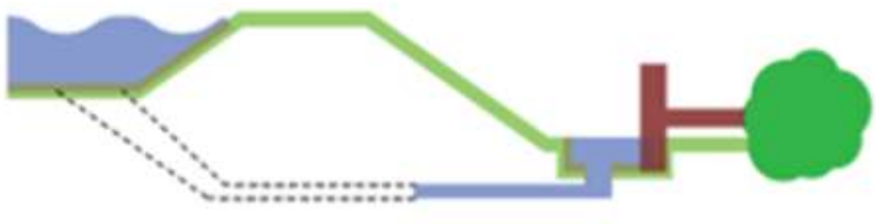
PFM 2



PFM 12

Does the presence of trees materially increase the risk from flooding at the DCTWRP?

PFM 2 *Oak tree on slope of protected side topples creating a seepage path*



During reservoir loading, high winds cause an oak tree on the slope of the protected side of the berm to topple. The fallen tree dislodges a root ball shortening the seepage path through the berm. The head from water in the reservoir drives seepage, which egresses in the cavity left by the root ball. Piping of the foundation soil initiates at the root-ball cavity and backward erosion occurs until a pipe forms to the reservoir. Rapid erosion enlarges the pipe until the crest of the berm collapses and water rushes into the plant site.

Risk drivers

Favorable factors

- Well maintained vegetation
- Modern, well-documented berm and wall construction
- Extensive soil testing
- Normally unsaturated soil
- Ample warning time to move people out
- Time for intervention

Adverse factors

- Possible flash flooding – little or no warning
- Undetected damage caused by seismic events
- Flood loads could be in place longer than anticipated
- Adverse erosion (e.g., animal burrows) could go undetected

Expert elicitation

USACE guidance

Likelihood of Failure	Estimated Likelihood
REMOTE	Likelihood<1/1,000,000
LOW	1/1,000,000< Likelihood<1/100,000
MODERATE	1/100,000< Likelihood<1/10,000
HIGH	1/10,000< Likelihood<1/1,000
VERY HIGH	Likelihood>1/1,000

Effect of wind on trees

Wind Speed (mph)	Impact on Trees
<30	LOW, <1/100,000
30-50	20 percent chance of losing at least one tree
50-70	67 percent chance of losing at least one tree
>70	Virtually certain to lose at least one tree

Expert elicitation for the probability of fatalities

Case	Water Surface Elevation [ft, NGVD29]	Description	Probability of Fatalities
1	<700	Water is lower than the toe of the structure	REMOTE, <1/1,000,000
2	700 to 710	Water on levee. Contractors and visitors evacuate.	LOW, <1/100,000
3	710 to 713	Water approaching 1/200 year level.	MODERATE, <1/10,000
4	713 to 715	Water begins to reach levee superiority.	VERY HIGH, <1/1,000
5	>715	Water exceeds levee superiority; overtopping occurs.	<1/100

Expert elicitation of the probability of wall failure due to tree toppling

Case	Likelihood of Floodwall Failure
PFM 6: Redwood tree topples and damages floodwall	LOW <1/100,000
PFM 10: Oak tree on flood side of floodwall topples and damages wall	LOW <1/100,000

				Seepage	Stability	
Section	Loading Condition	Water Surface Elevation (ft, NGVD29)	Analysis Method	Ave. Exit Gradient (ft/ft)	Rapid Drawdown	Critical Flood
					Floodside Slope (FOS)	Landside Slope (FOS)
South Berm	SPF	713.5	Steady State	<0.5	1.72	1.32
South Berm	SPF	713.5	Transient	<0.5	n.a.	>1.4
East Berm	PMF	717.0	Steady State	<0.5	1.86	1.44
Floodwall	SPF	713.5	Steady State	0.7	n.a.	n.a.
Floodwall	SPF	713.5	Transient	<0.5	n.a.	n.a.

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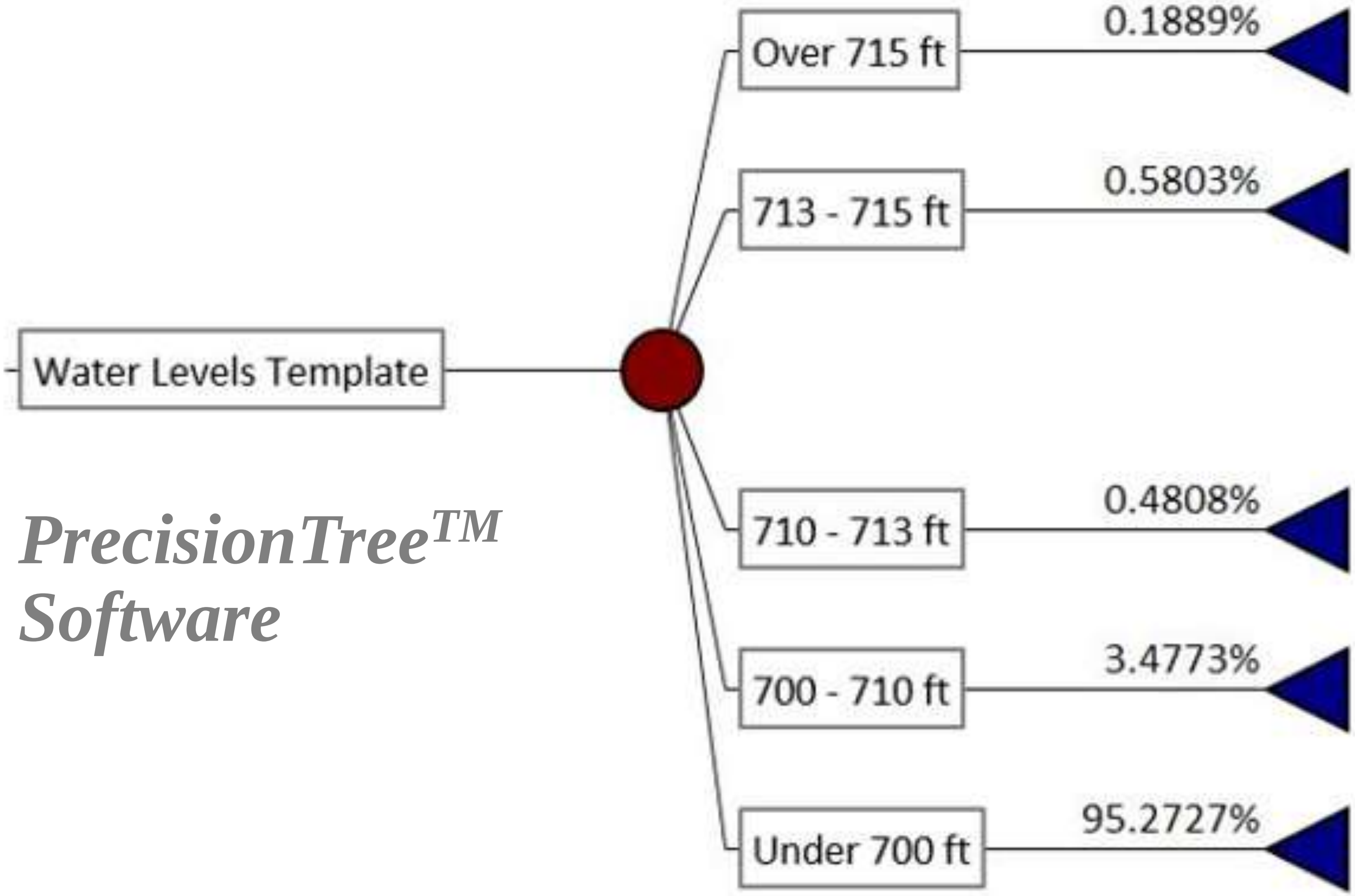
Effect of seepage analysis on stability

Estimates of the probability of slope instability based on deterministic analysis

Basin Condition	Tree Safe	Tree on Slope Thrown	Tree on Crest Thrown	Undetected Erosion
Low Water	LOW <1/100,000	REMOTE <1/1,000,000	REMOTE <1/1,000,000	REMOTE <1/1,000,000
Medium Water	MODERATE <1/10,000	LOW <1/100,000	LOW <1/100,000	LOW <1/100,000
High Water	HIGH <1/1,000	MODERATE <1/10,000	MODERATE <1/10,000	MODERATE <1/10,000

Basin Condition	Tree Safe	Tree on Slope Thrown	Tree on Crest Thrown	Undetected Erosion	With Burrow >3 Ft.
Low Water	REMOTE <1/1,000,000	REMOTE <1/1,000,000	REMOTE <1/1,000,000	REMOTE <1/1,000,000	REMOTE <1/1,000,000
Medium Water	REMOTE <1/1,000,000	REMOTE <1/1,000,000	REMOTE <1/1,000,000	REMOTE <1/1,000,000	REMOTE <1/1,000,000
High Water	REMOTE <1/1,000,000	REMOTE <1/1,000,000	LOW <1/100,000	LOW <1/100,000	LOW <1/100,000

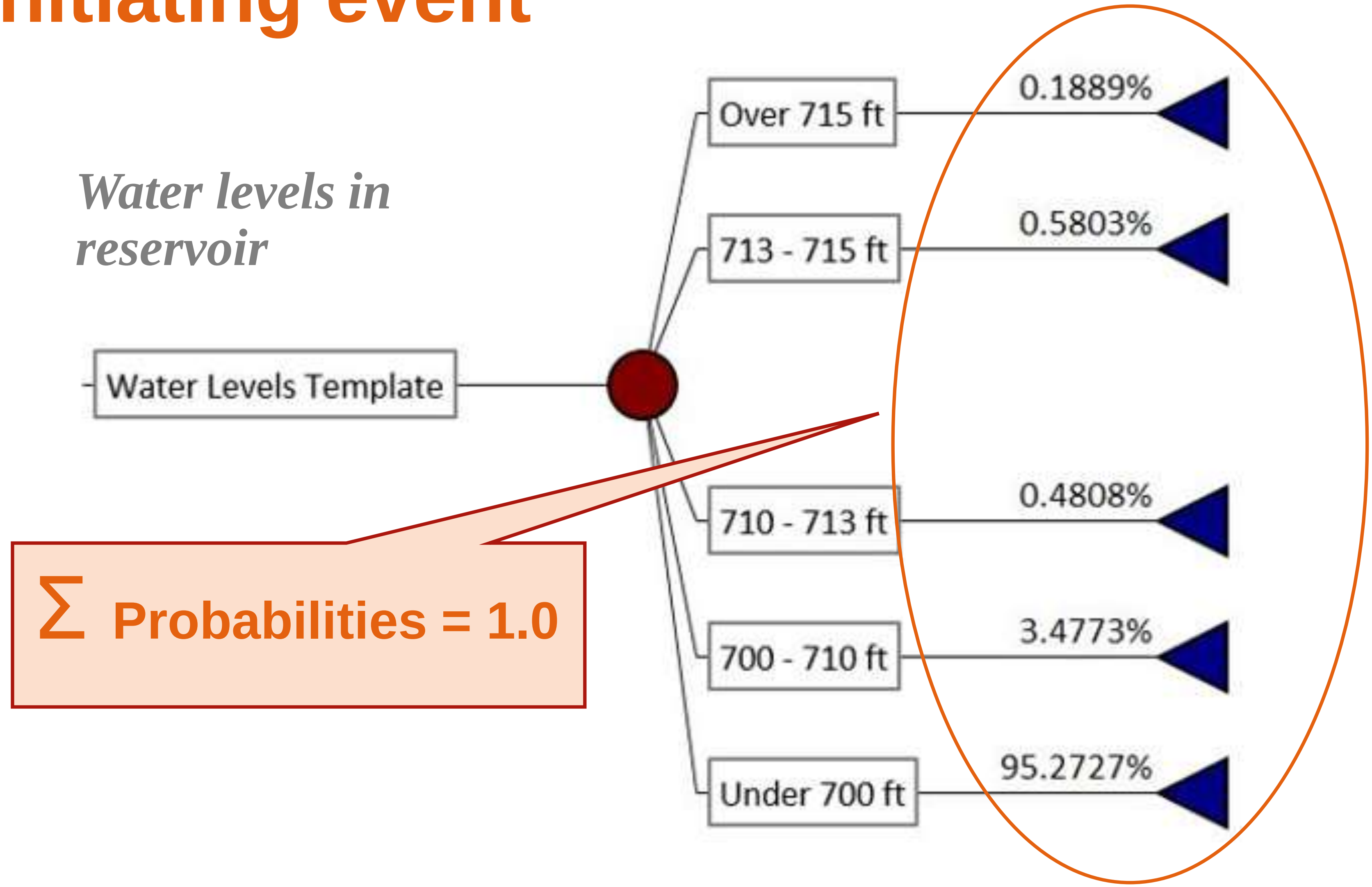
Initiating event



PrecisionTree™ Software

Initiating event

Water levels in reservoir



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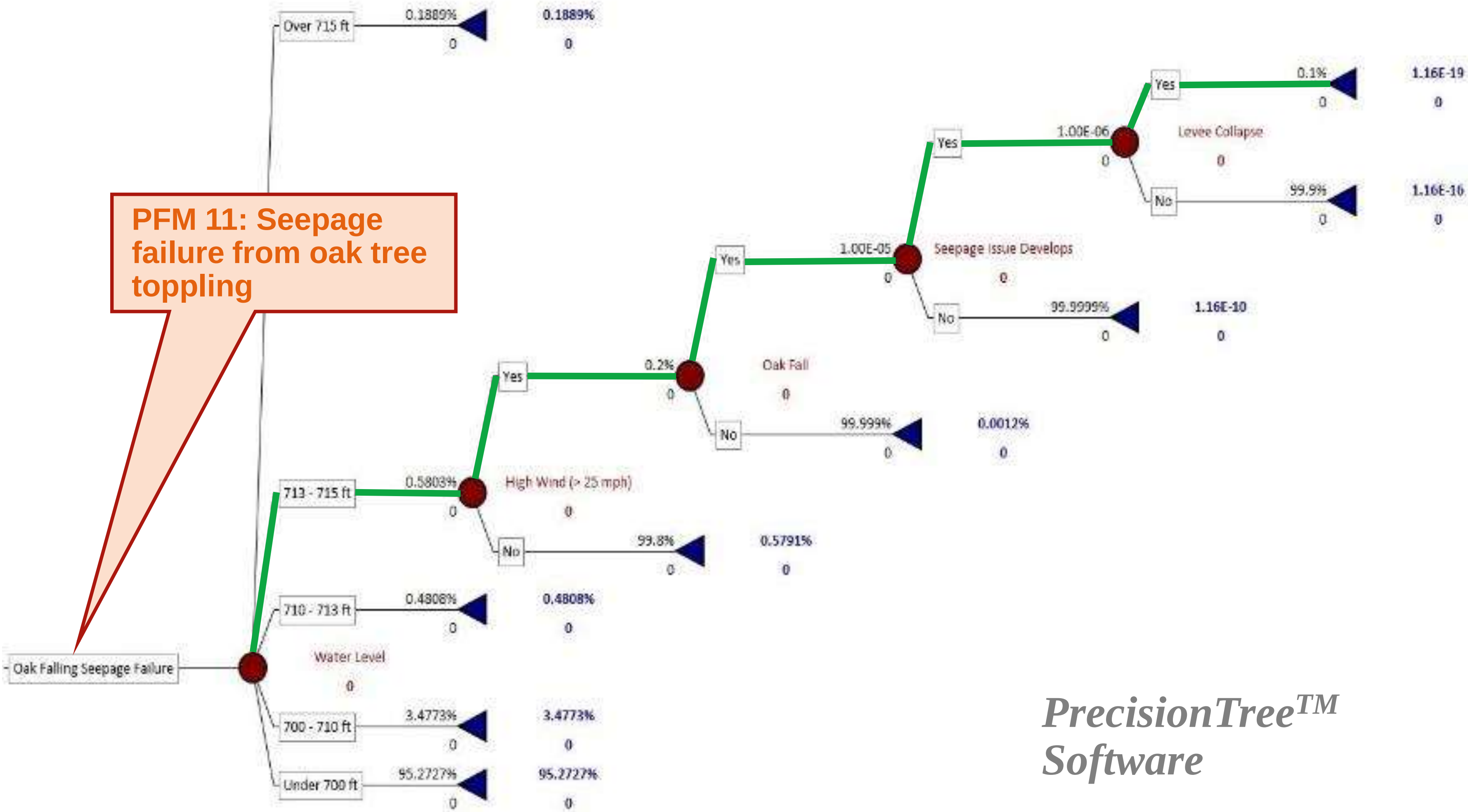
Building the tree



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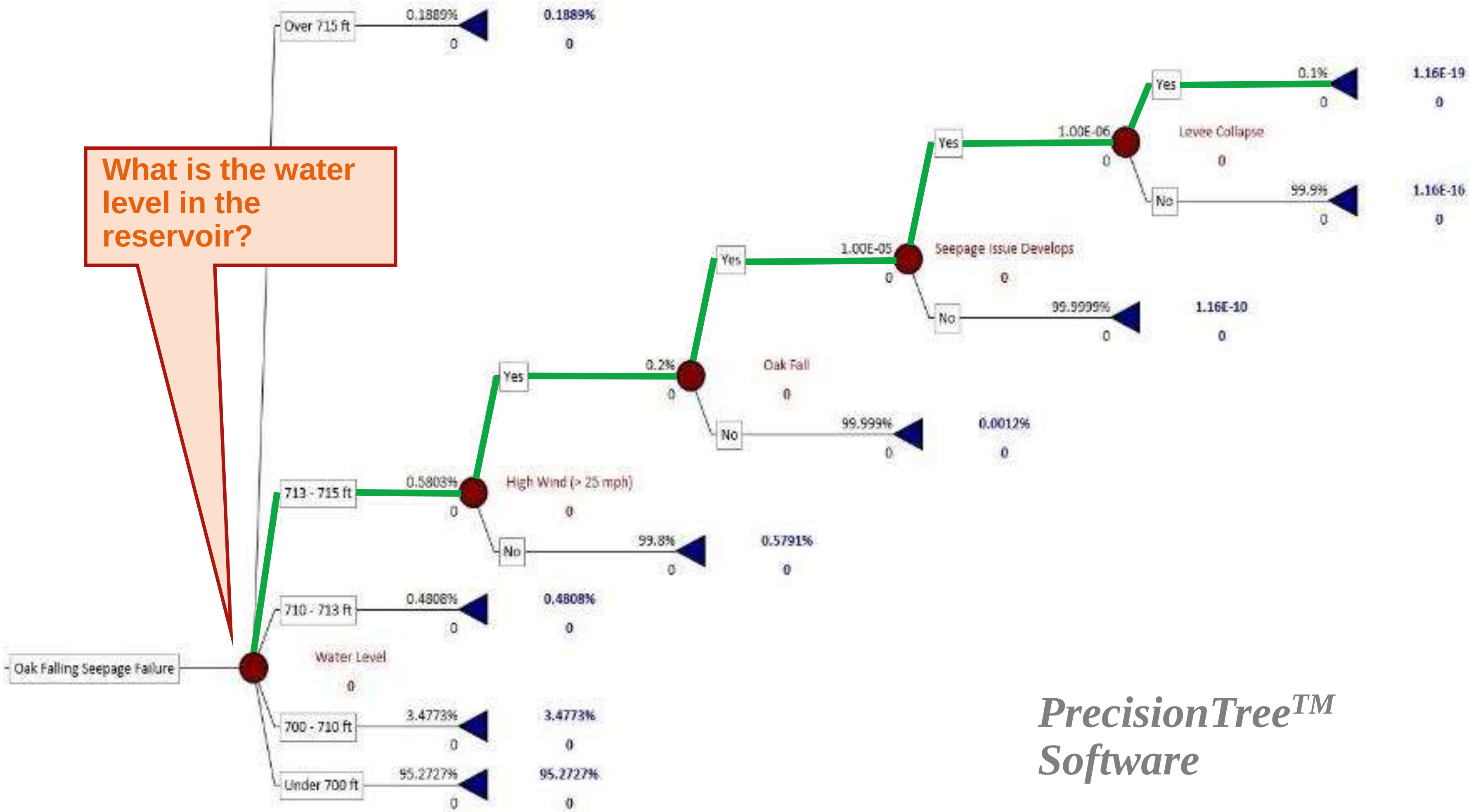

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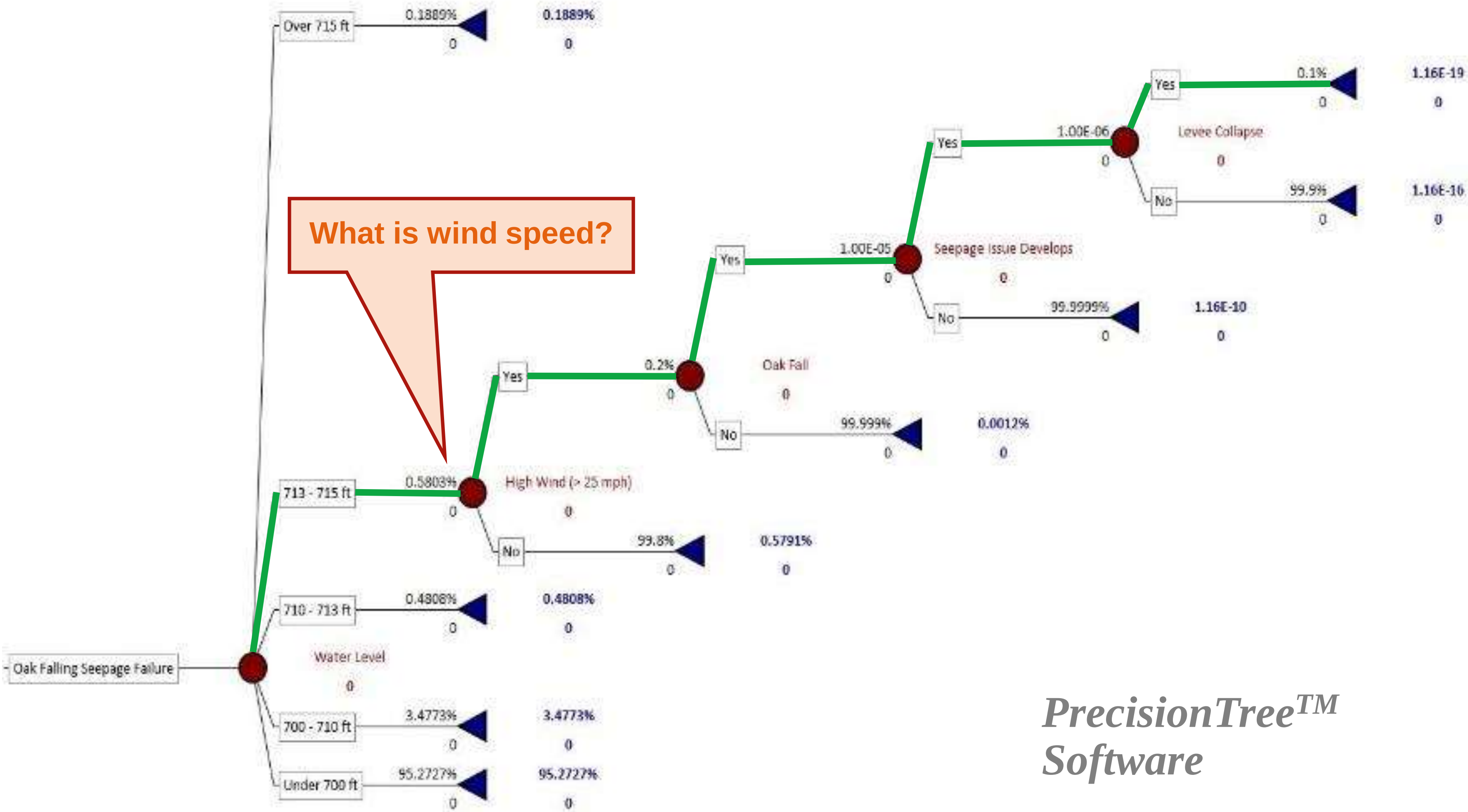

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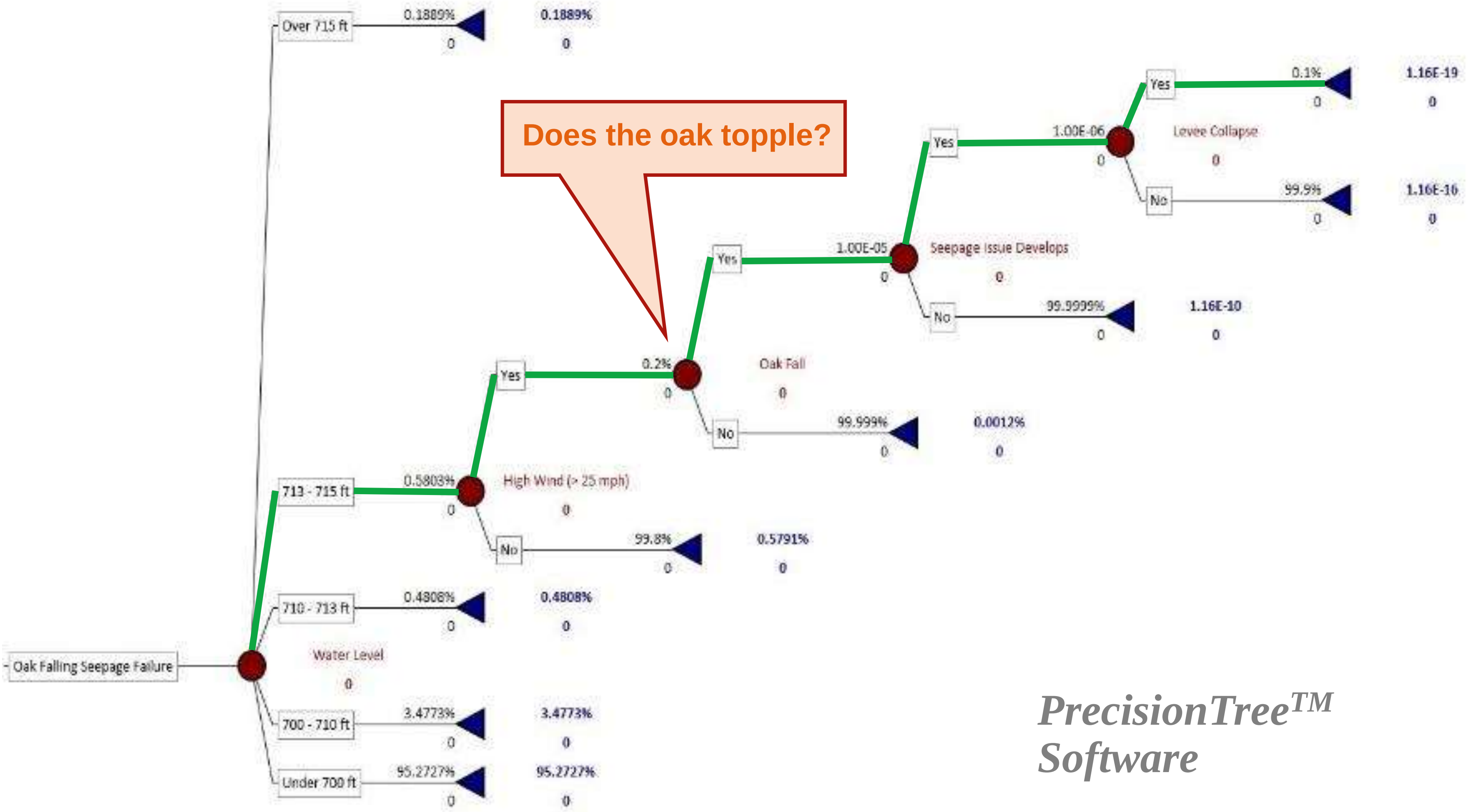
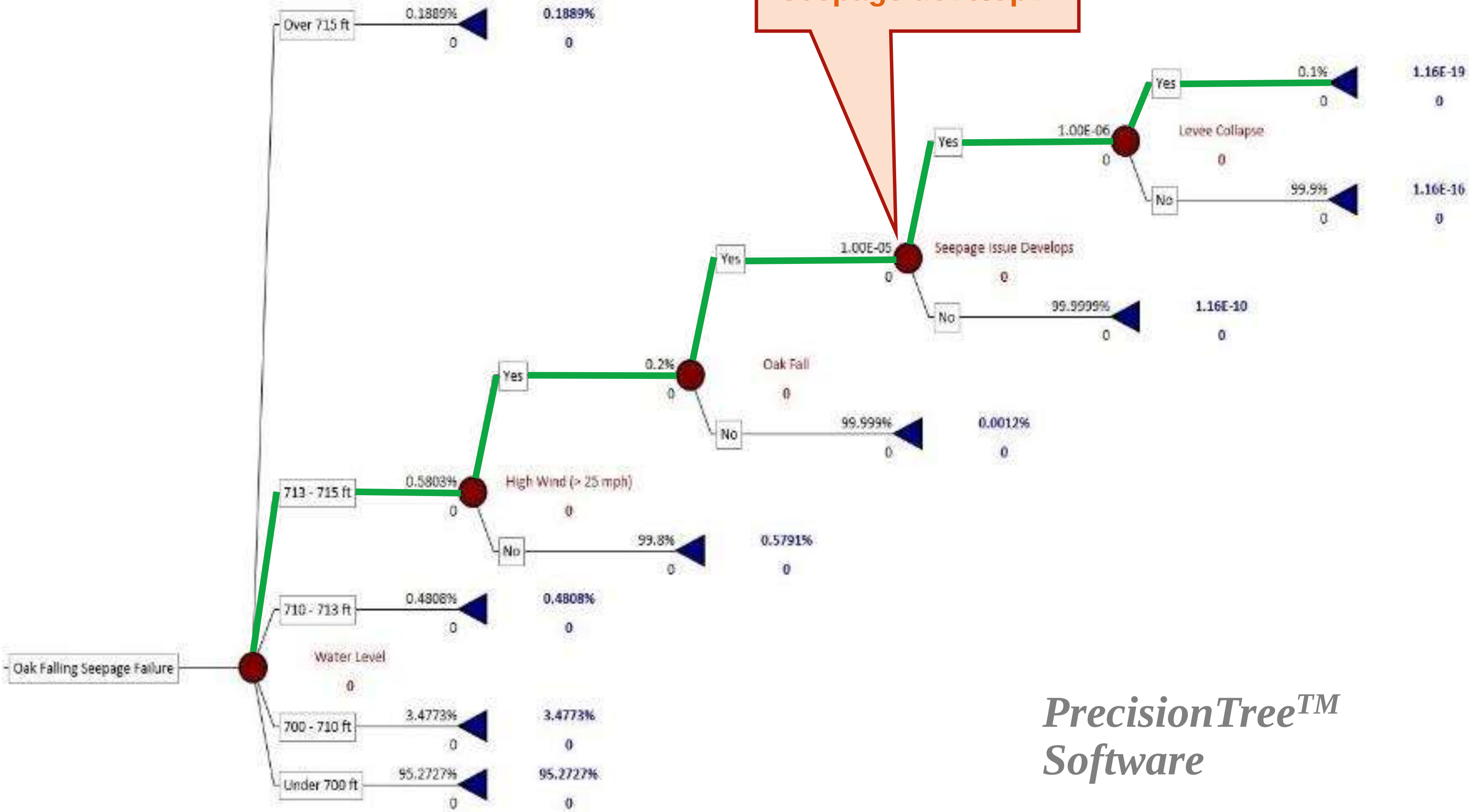


PrecisionTree™ Software

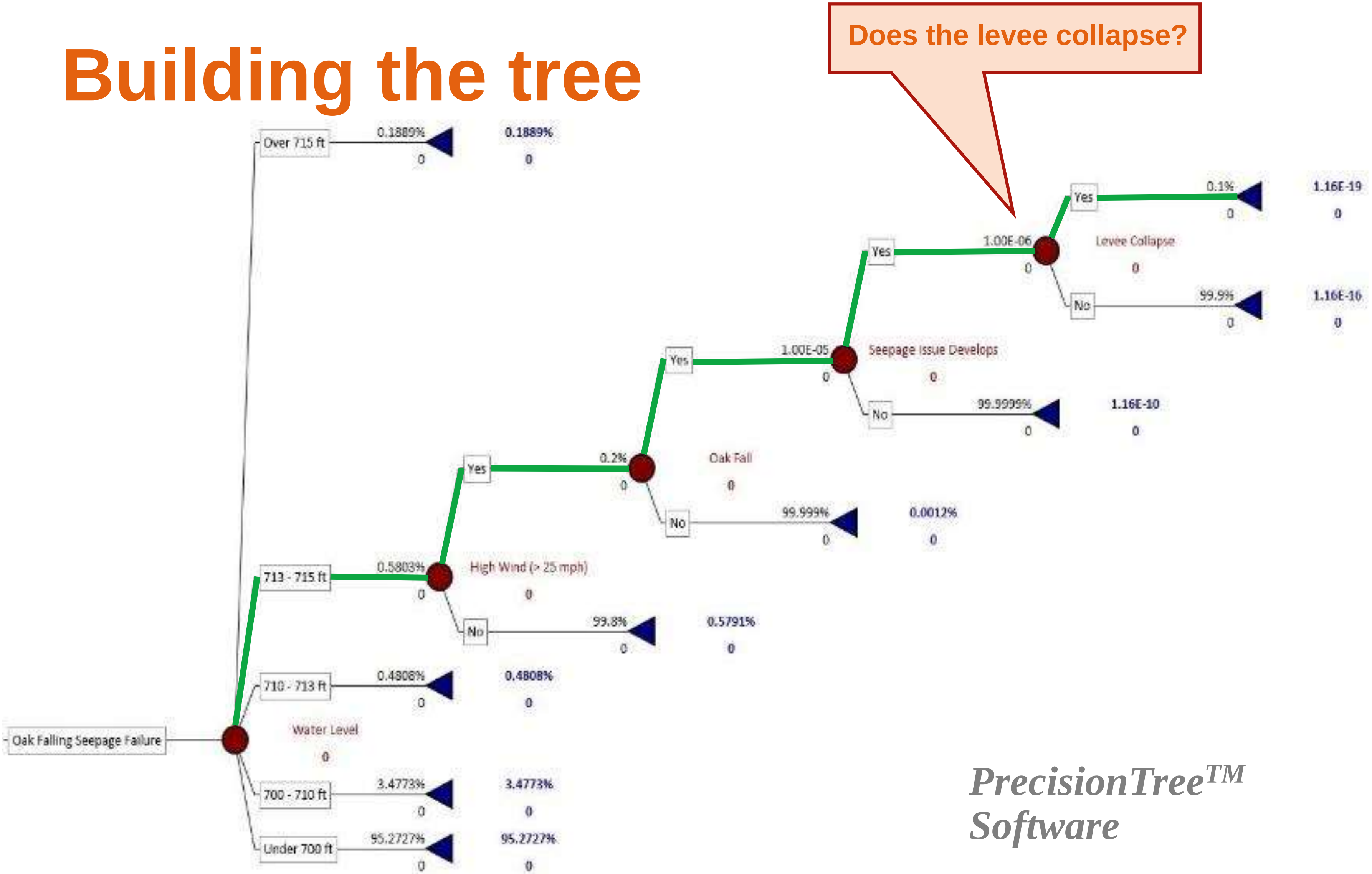
Building the tree

Does steady-state seepage develop?



PrecisionTree™ Software

Building the tree



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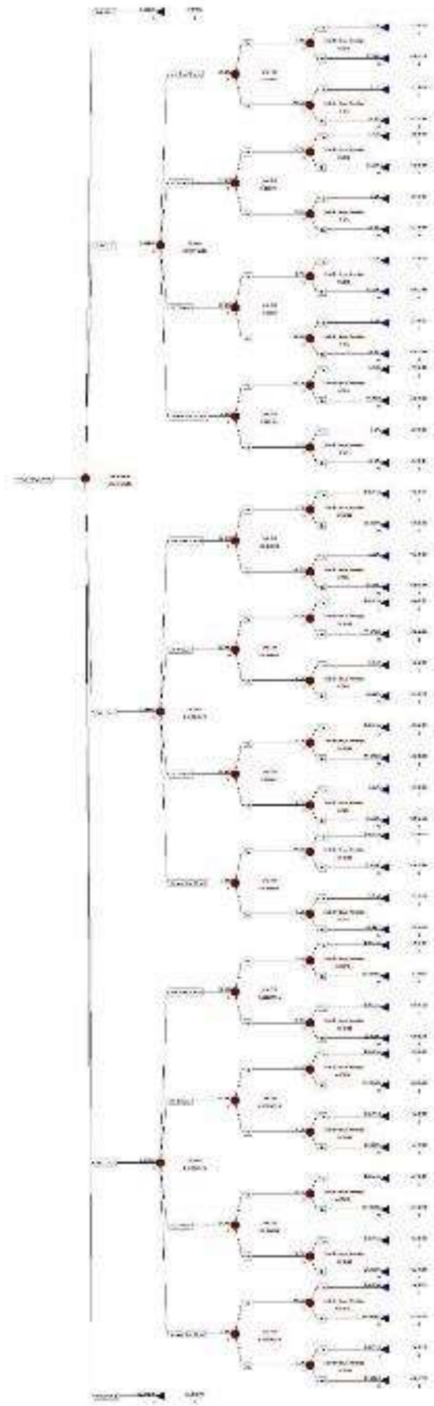

Example tree

One tree for each PFM

Trees are built using

- Calculated probabilities
- Expert elicitation

PrecisionTree^{TM} keeps track of complicated event nodes and event probabilities

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EAD Results

PFM	Description	Probability of Failure		Expected Annual Damage	
		Total ($x\ 10^{-3}$)	Added by Trees ($x\ 10^{-8}$)	Total	Added by Trees
1	Redwood topples, creates seepage path	1.889	1.303	$98,904	$0.68
2	Oak on protected side topples, creates seepage path	1.889	1.303	$98,904	$0.68
3	Oak on flood side topples, creates seepage path	1.889	1.303	$98,904	$0.68
4	Oak on protected side topples, creates slope instability	1.894	19.03	$99,159	$9.96
5	Oak on flood side topples, creates slope instability	1.894	19.03	$99,159	$9.96
6	Redwood topples, damages floodwall	1.890	13.03	$98,908	$6.82
7	Burrows create seepage path	0.0000463	0.179	$2	$0.09
8	Erosion causes seepage path	1.890	9.761	$98,906	$5.11
9	Erosion causes slope instability	1.889	66.31	$98,936	$34.71
10	Oak topples, damages floodwall	1.890	13.03	$98,904	$6.82
11	Oak on crest topples, creates seepage path	1.889	2.802	$98,904	$1.47
12	Oak on crest topples, creates slope instability	1.894	19.03	$99,159	$9.96

EAD Results

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Contribution of Trees to Failure

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Expected Annual Damage

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Contribution of Trees to EAD

Findings

	Return Period (years)	Chance of Dying	Annual Cost of Failure
Standard Project Flood (SPF)	1/200		
Overtopping Failure	~ 1/525	~ 1/20,000	~ $99,000
Tree-caused Failure	< 1/15,000	< 1/555,000,000	< $35.00

All PFMs had a probability of failure of < 0.02 percent, or about once in 500 years

Consequences = $52M

EAD = $100K

Contribution from trees = $0.68 – $35.00 per year

Findings

	Return Period (years)	Chance of Dying	Annual Cost of Failure
Standard Project Flood (SPF)	1/200		
Overtopping Failure	~ 1/525	~ 1/20,000	~ $99,000
Tree-caused Failure	< 1/15,000	< 1/555,000,000	< $35.00

The presence of trees do not materially increase the risk from flooding at the DCTWRP.

Vary soil permeability by factors of 10, 100, and 1000

		Contribution to Total EAD			
Sensitivity Case	Total EAD	From Overflow	From Seepage	From Seepage, No Tree Toppling	From Seepage, Tree Topples
Base Case, PFM 2	$98,903.58	$98,880.22	$23.36	$22.68	$0.68
Seepage is 10 x more likely	$98,924.97	$98,880.22	$44.74	$37.92	$6.82
Seepage is 100 x more likely	$99,138.77	$98,880.22	$258.54	$190.36	$68.18
Seepage is 1,000 x more likely	$101,276.81	$98,880.22	$2,396.59	$1,714.74	$681.85

ARCADIS Design & Consultancy for natural and built assets

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EAD varies from $0.68 to $680 (out of ~$100,000)

Recommendations

Recognize the threat and implement effective O&M

Aggressively monitor the health of vegetation, take timely action when needed

Prepare and implement a plan to remove redwood trees as they age

Prepare and implement a plan for aggressive flood fighting

Prepare and implement a monitoring plan for berm and floodwall safety

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