# TRANSITIONING TO RISK-INFORMED DESIGNS FOR DAMS AND LEVEES

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# OUTLINE

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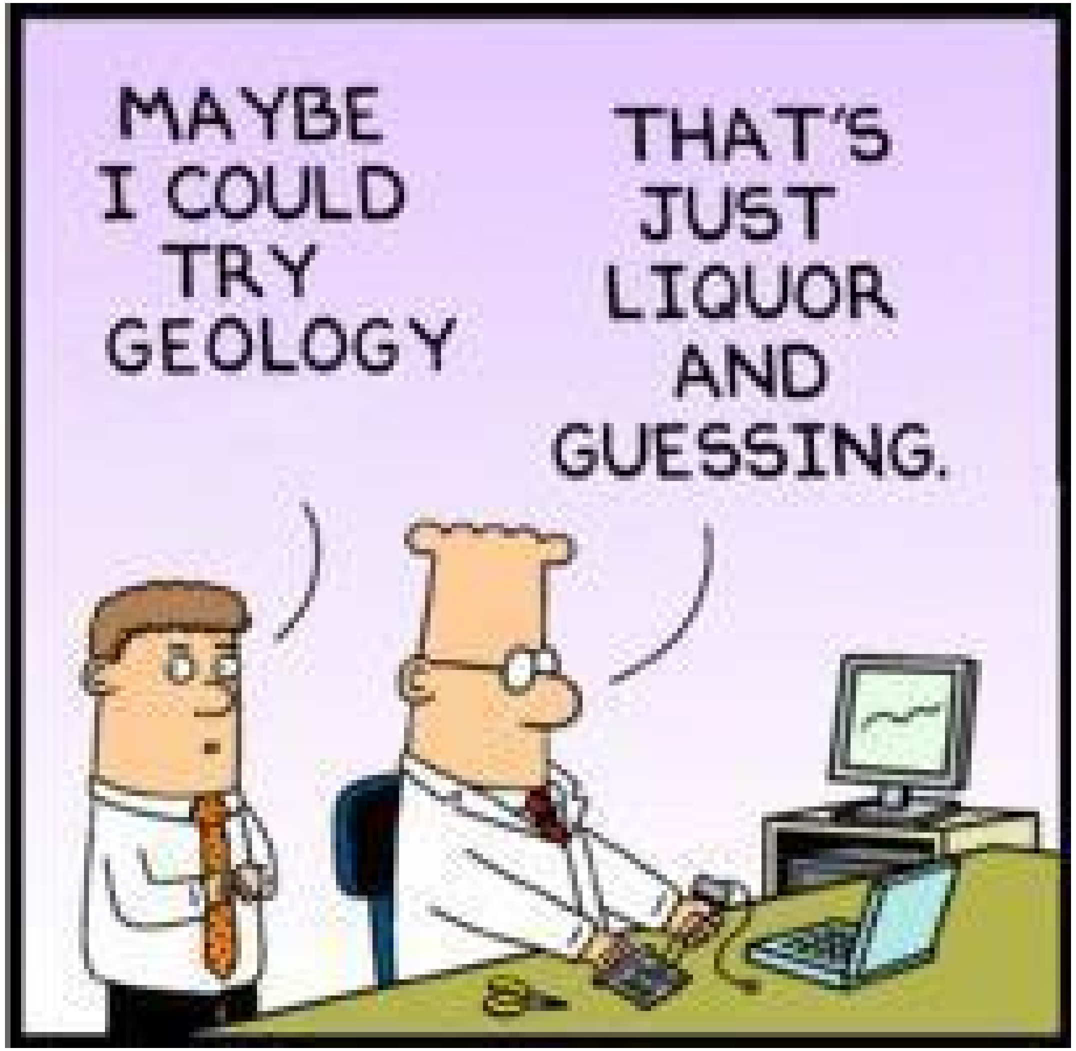
- USACE
- Background
- Levee Design Manual – 3 Problems
- Example – Moose Creek
- Example – Herbert Hoover Dike



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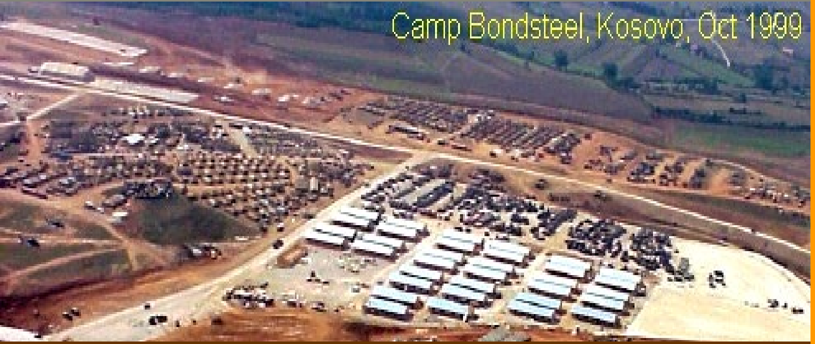
# CORPS OF ENGINEERS

# Military Programs

- Military Construction
- Base Operations
- Environmental Support
- Geospatial Engineering




# Real Estate

Acquire, Manage & Dispose

- DOD Recruiting Facilities
- Contingency Operations

# Homeland Security

- Critical Infrastructure Protection
- The Infrastructure Security Partnership
- Contingency and Disaster Operations

# Interagency Support

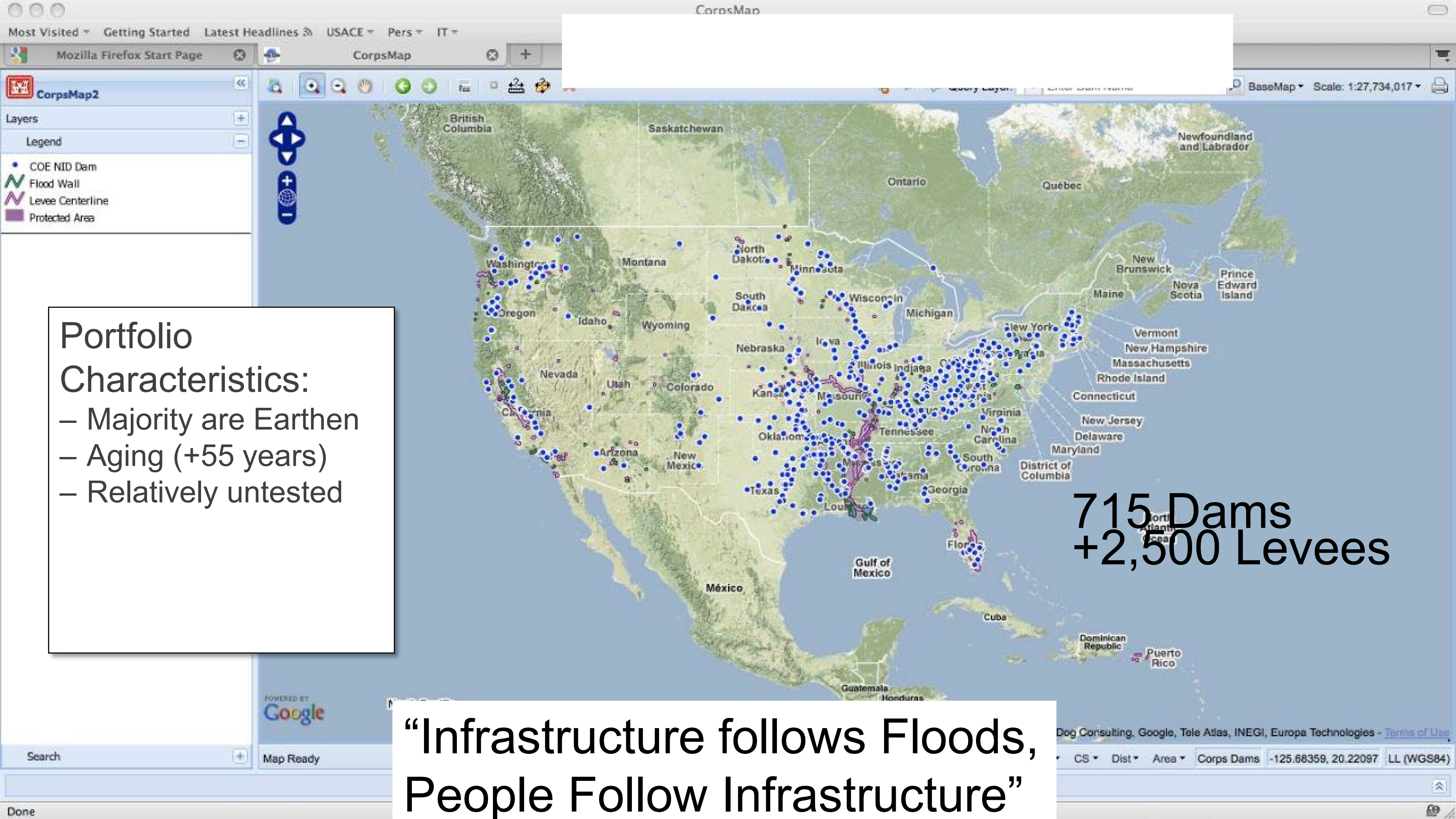
- DOD
- Federal
- State
- Local
- International

# Research & Development

- Military Engineering
- Terrain & Geospatial
- Structures
- Environment
- Water Resources

# Civil Works

- Navigation, Hydropower
- Flood control, Shore Protection
- Water Supply, Regulatory
- Recreation, Disaster Response
- Environmental Restoration




Portfolio Characteristics:

– Majority are Earthen
– Aging (+55 years)
– Relatively untested

715 Dams
+2,500 Levees

"Infrastructure follows Floods, People Follow Infrastructure"

# USACE INFRASTRUCTURE



## Dams

- 715 Dams
- 80% Earthen and 20% Concrete Gravity on Improved Foundations
- PAR of +12.8M
- Property at risk = +1T
- Total length of 267 miles
- Average age = +55
- Pass extreme flows in controlled manner

## Levees

- 2,500 levee segments
- 95% Earthen, 5% Concrete Floodwall on unimproved foundations
- PAR of +9.5M
- Property at risk = +$1.3T
- Total length of 14,700 miles
- Average age = +55
- Pass extreme flows in uncontrolled manner

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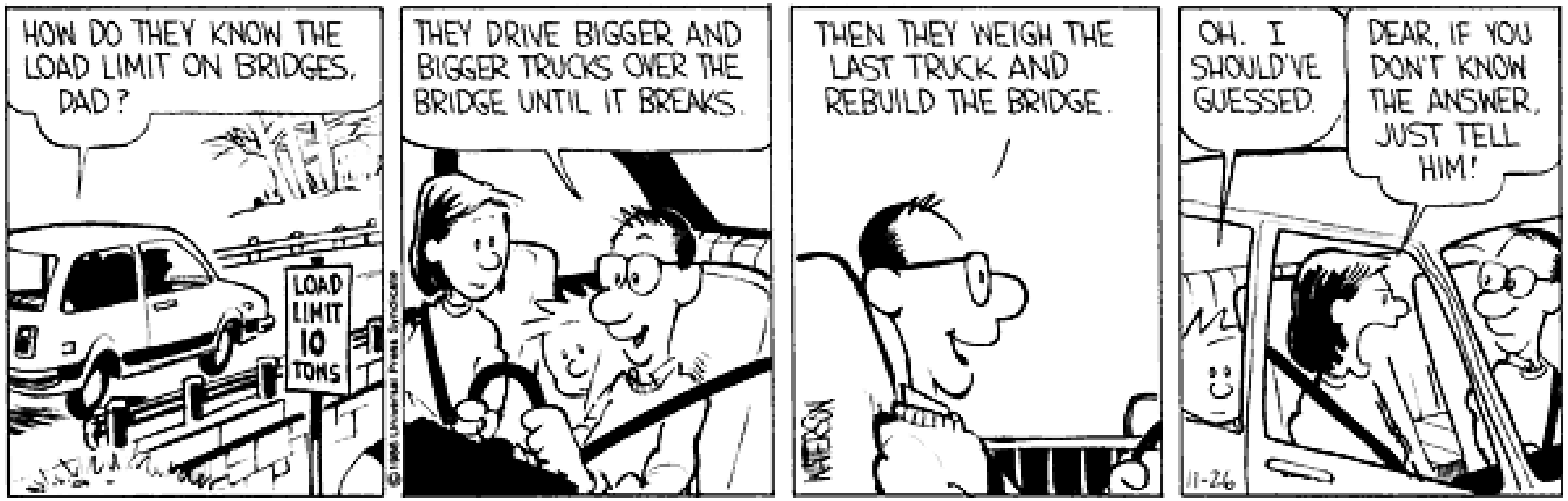
# BACKGROUND



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# HISTORY – WATER RETAINING STRUCTURES (DAMS AND LEVEES)

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- Engineering organizations, private consultants, and government agencies have been using regulations, manuals, and guidance published by the Corps of Engineers for nearly 75 years
- The guidance currently published aggregates many of the lessons learned by the profession from their experience observing the performance of dams and levees worldwide
- The approach taken by our predecessors, to pass that knowledge to future generations, has led to an improvement in the design and construction processes over the course of the last 75 years

# THE UNDERLYING ISSUE

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# FOUNDATIONS, FILTERS, AND INTERNAL EROSION

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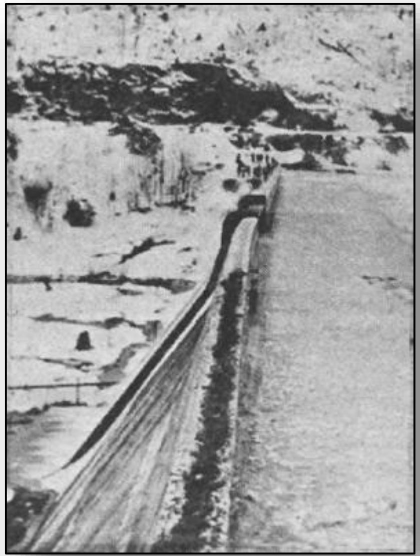

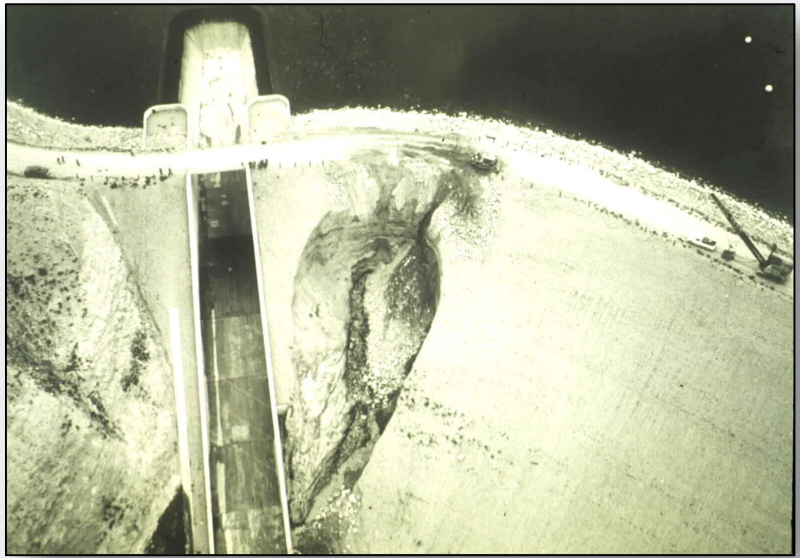

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# CONDUITS AND EARTHQUAKES

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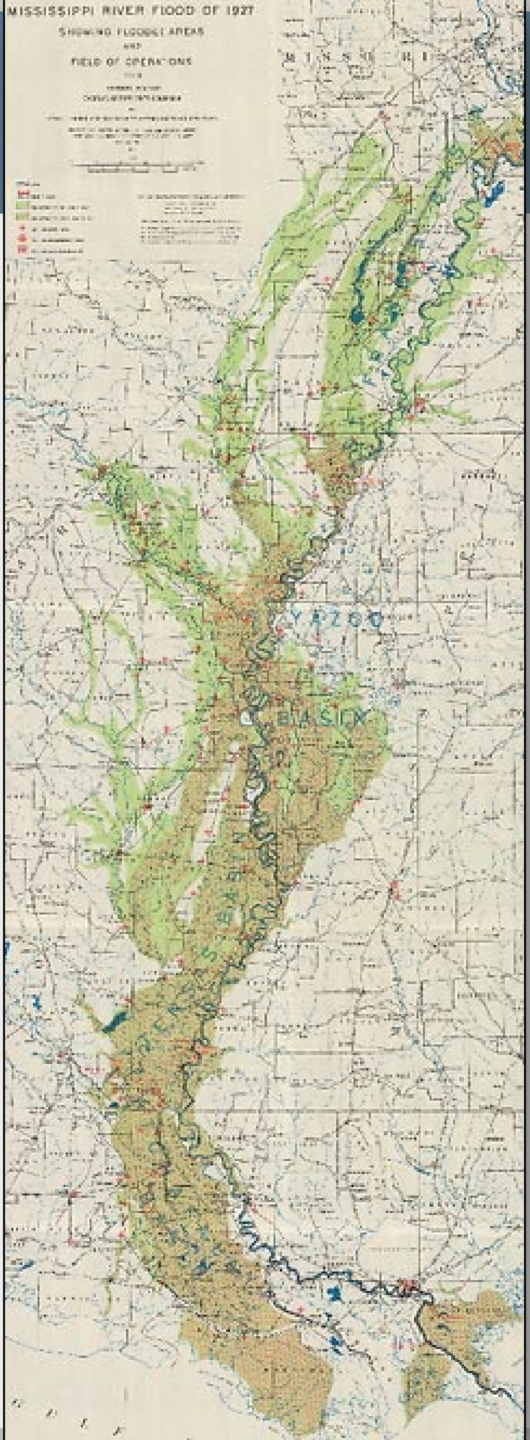
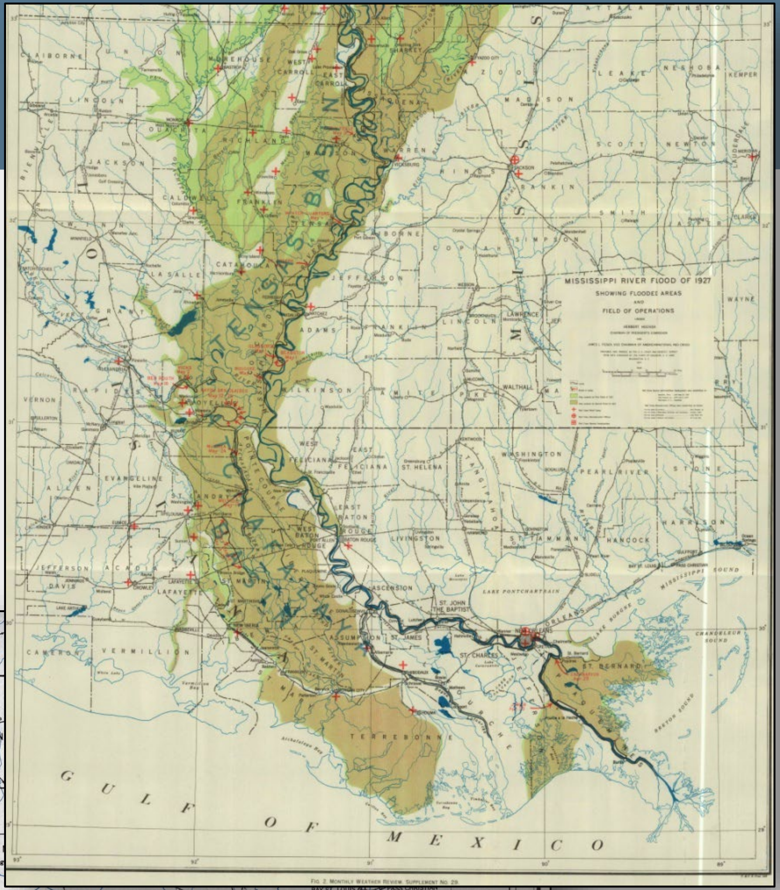

MISSISSIPPI RIVER FLOOD OF 1927
SHOWING FLOODED AREAS
AND
FIELD OF OPERATIONS
YAZOO
BASIN


WILKINSON
WEST FELICIANA
EAST FELICIANA
ST. HELENA
ST. LANDRY
EAST BATON ROUGE
WEST BATON ROUGE
LIVINGSTON
ASCENSION
ST. JOHN THE BAPTIST
LAKE PONTCHARTRAIN
ST. MARTIN
ASSUMPTION
ST. JAMES
ST. CHARLES
ORLEANS
ST. BERNARD
LAFAYETTE
TERREBONNE
CHANDELEUR SOUND
BRETON SOUND
GULF OF MEXICO


MISSISSIPPI RIVER FLOOD OF 1927
SHOWING FLOODED AREAS
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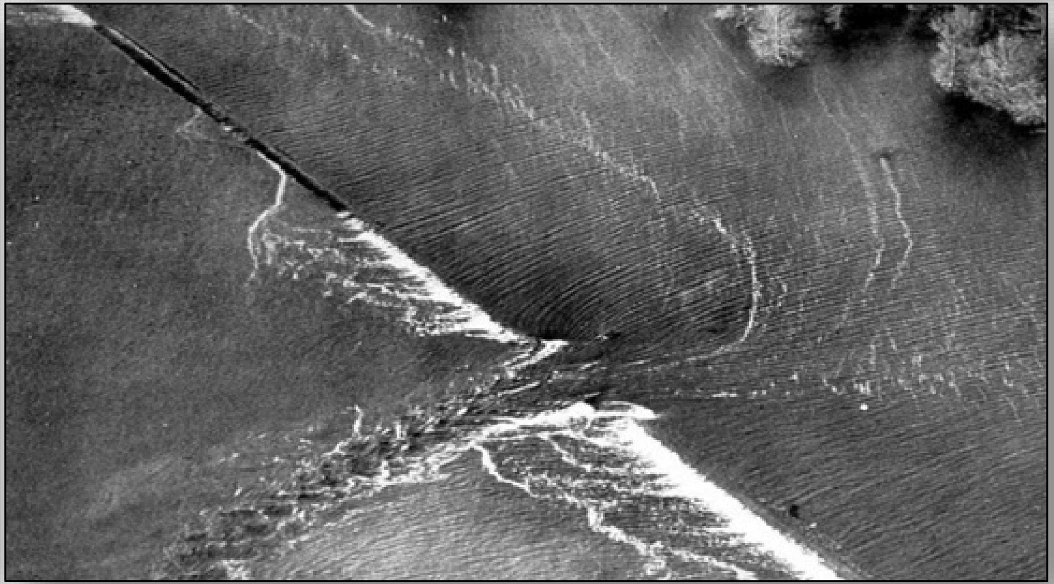
# 1927 LEVEE PERFORMANCE





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# LEVEE DESIGNS 1927 – 1970'S



- Examinations of levee failures – led directly to levee design standards
- Geomorphology studies
- Much R&D at the Waterways Experiment Station

- Stability
- Underseepage
- Focused on Lower Mississippi




# DESIRE TO REVISE LEVEE DESIGN MANUAL

3 Significant Problems Identified

# PROBLEM NO. 1

Not every levee conforms to levee geometry in the lower Mississippi

*"It's great if you are from the Lower Mississippi, but there's nothing about the types of designs we do here in ________________."*

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# FLOOD FIGHTING SAND LEVEES

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# 2011MISSOURI RIVER PERFORMANCE HISTORY

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# SEEPAGE BERM DESIGN

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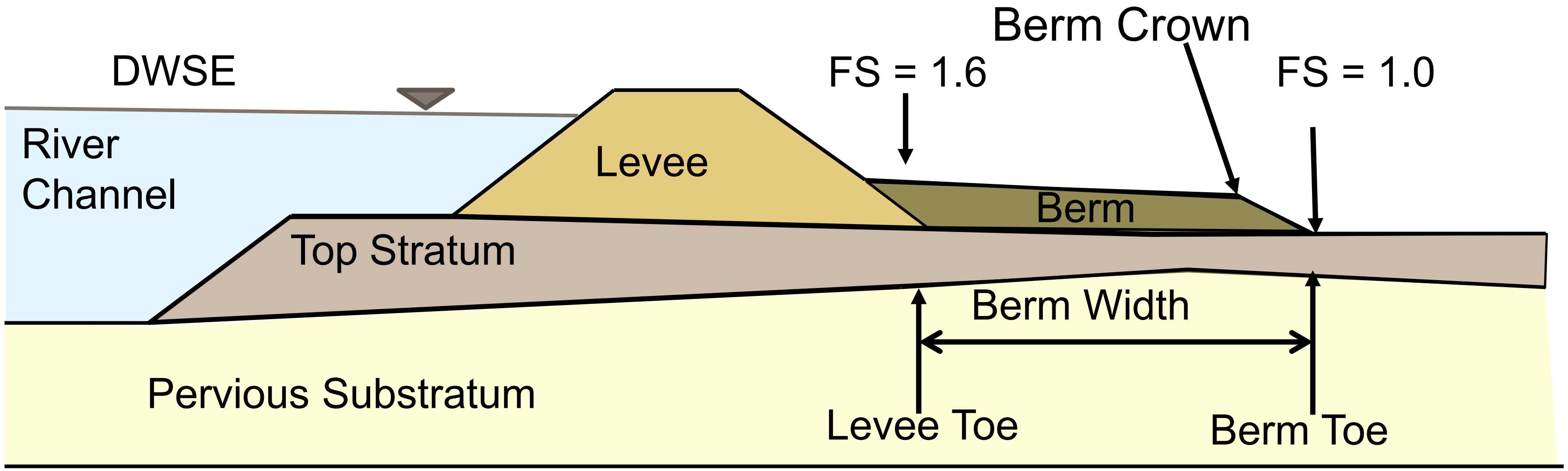


- Factors of safety called out
- Traditional dimensions discussed but requirements not set
- Past performance and engineering judgment are paramount

# PROBLEM NO. 2

We don’t have an analytical model for every failure mode

# MARCHAND LEVEE FAILURE 1983



# FLOW SLIDES IN SAND

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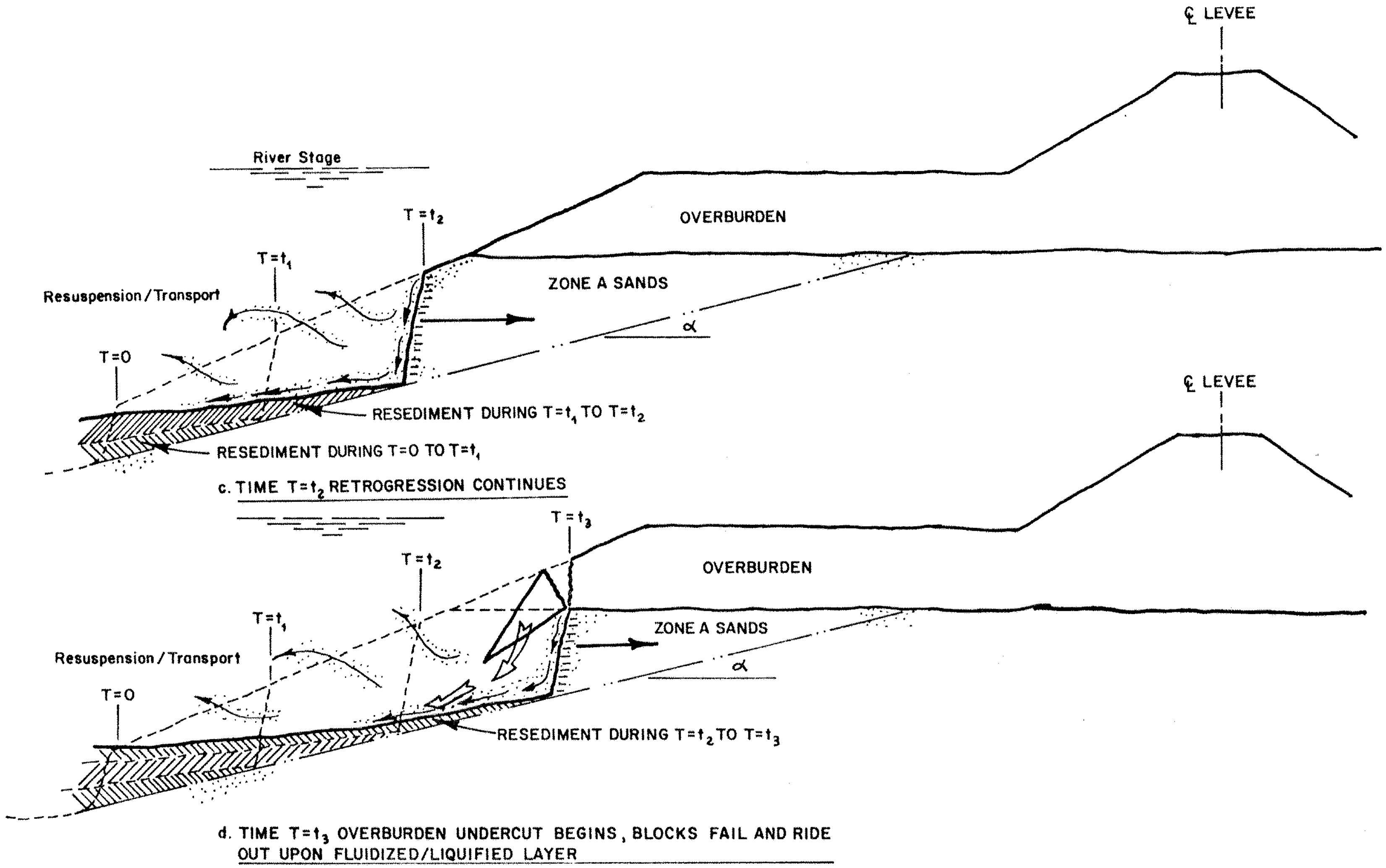

# INTERNAL EROSION



# PROBLEM NO. 3

We don’t have a model that incorporates intervention

# FLOOD FIGHTING




Levee did not fail, but internal erosion pipes projecting towards the river found in 2012.

Example Flood Fighting Evaluation

*"More than expected and, but for flood fighting, levee would have failed"*

Ensley Berm, Memphis 2011

# FLOOD FIGHTING



Possibly due to defects in riverside cap - fourth pipe formed and breached on June 13, 2011.

Example Flood Fighting Evaluation

*"Flood fighting occurred but levee failed"*

L-575 Breach, NW Atchison County Levee District, Hamburg Iowa 2011

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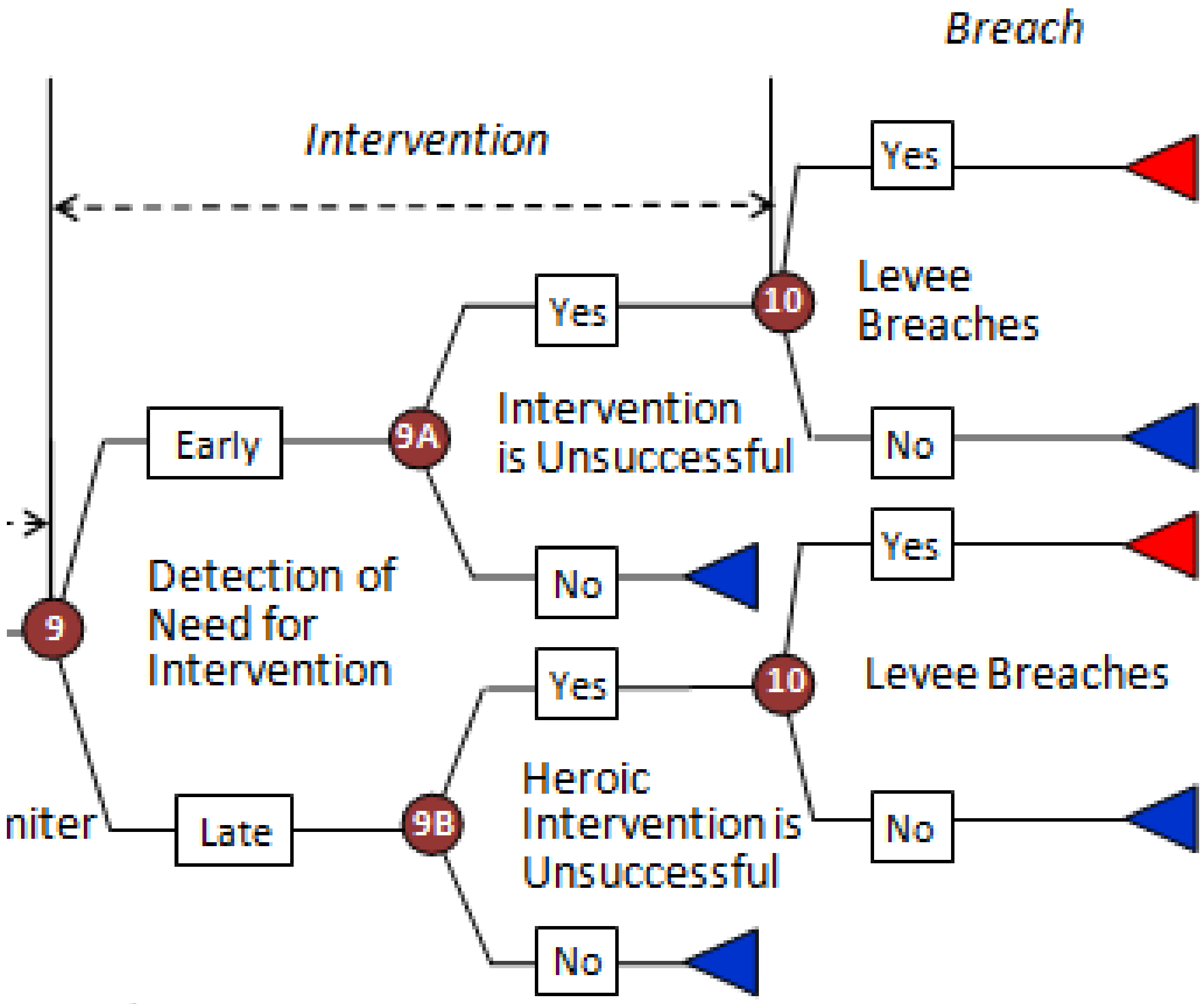
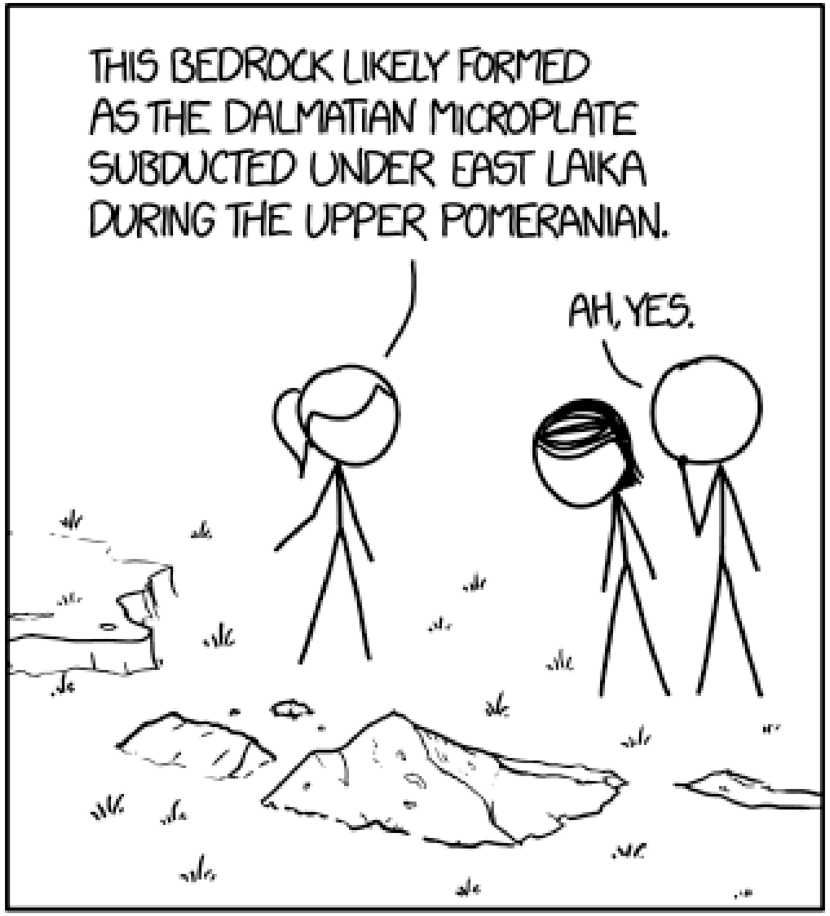


# THIS IS NOT THE INTERVENTION WE'RE TALKING ABOUT…



# GENERAL PROCESS AND EXAMPLES




GEOLOGY TIP: THERE ARE SO MANY MICROPLATES AND AGES THAT NO ONE REMEMBERS THEM ALL, SO IN A PINCH YOU CAN BLUFF WITH DOG BREEDS.

# GENERAL PROCESS

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1. Have a baseline Potential Failure Mode Assessment and risk assessment
2. Design project using traditional factors of safety
3. Calculate the risk for that design
4. Evaluate the tolerability of the design
5. Modify the design
6. Calculate the risk for that design
7. Evaluate the tolerability of the design

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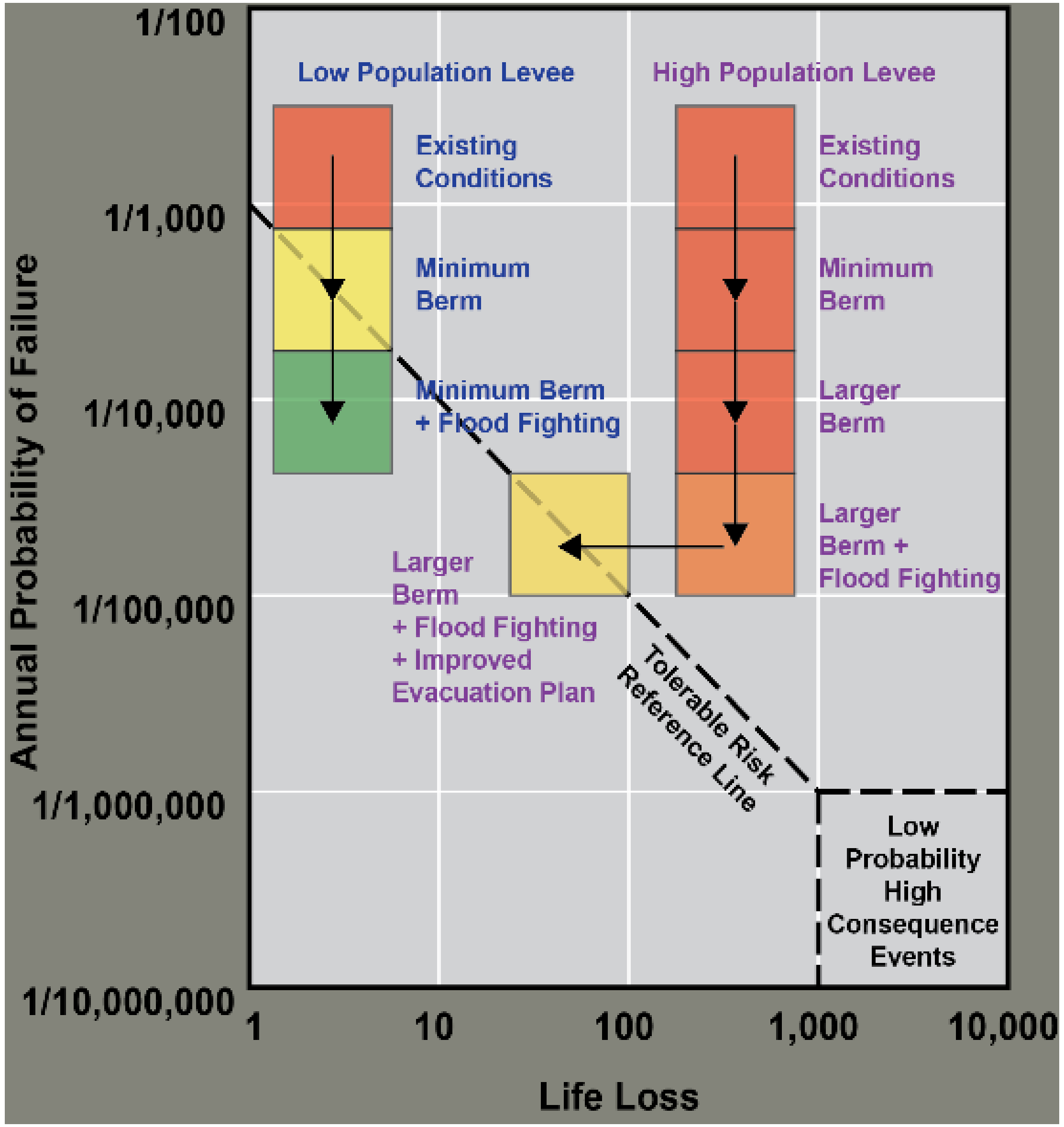

# MOOSE CREEK DAM

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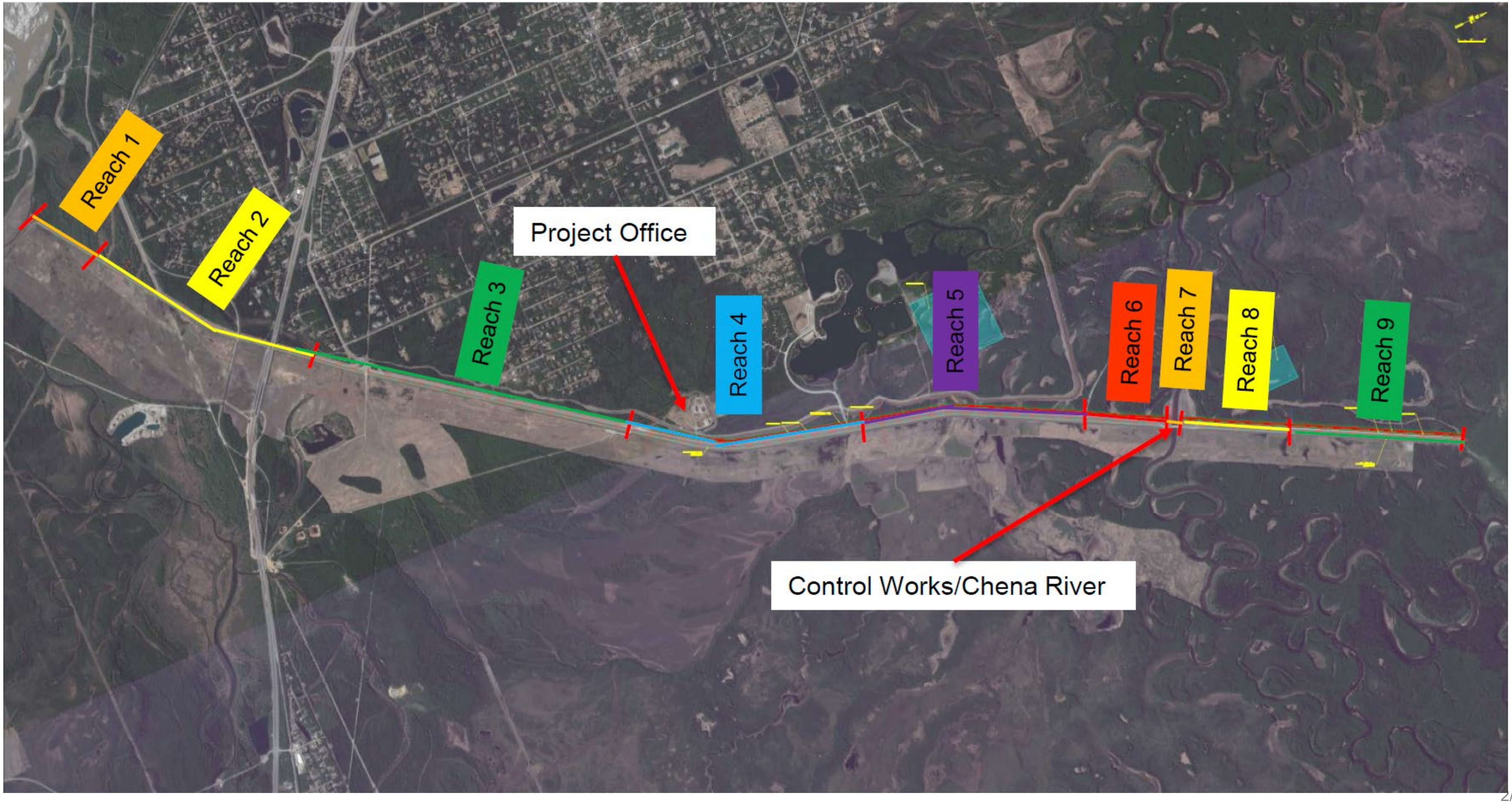

# MOOSE CREEK DAM

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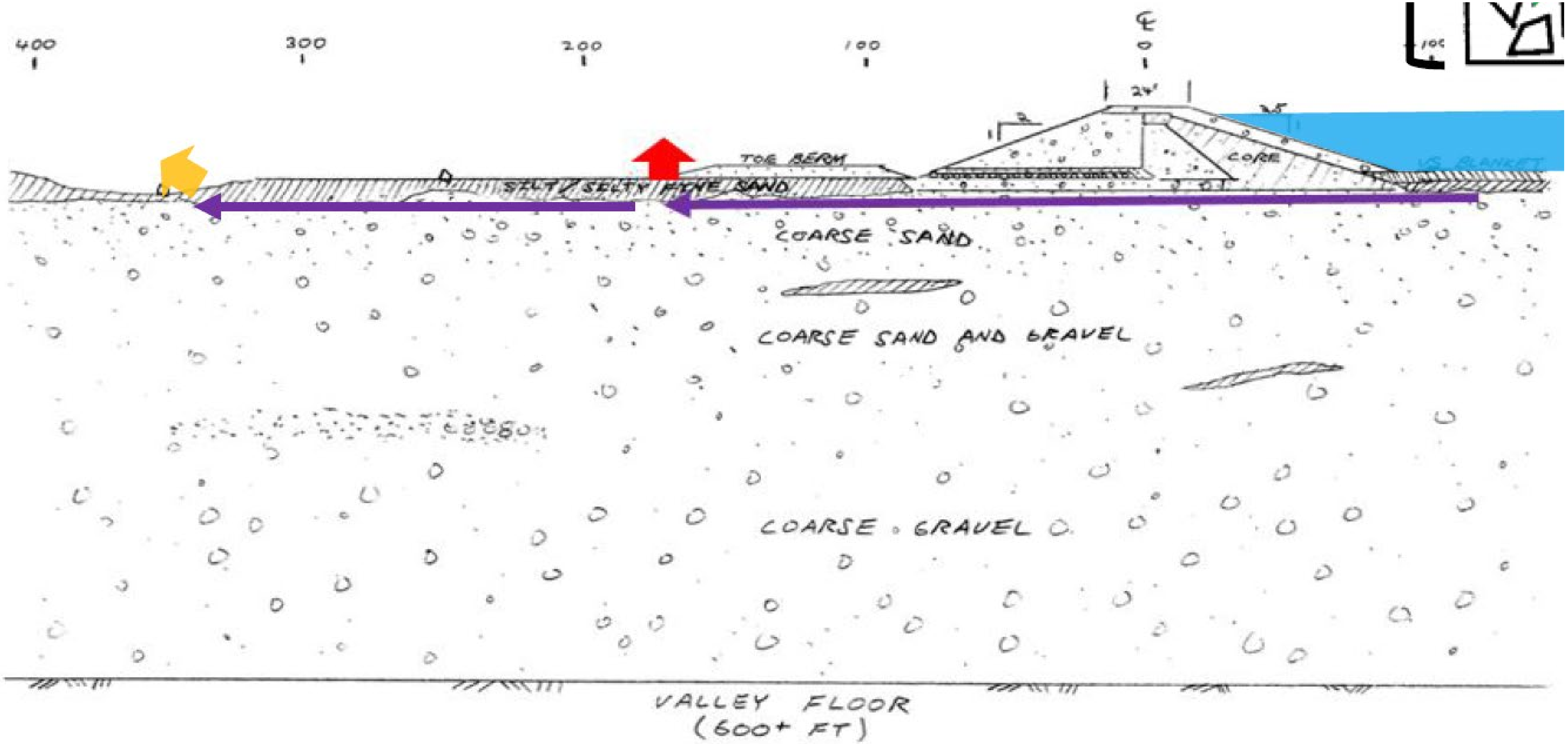

# MOOSE CREEK DAM – ALTERNATIVE

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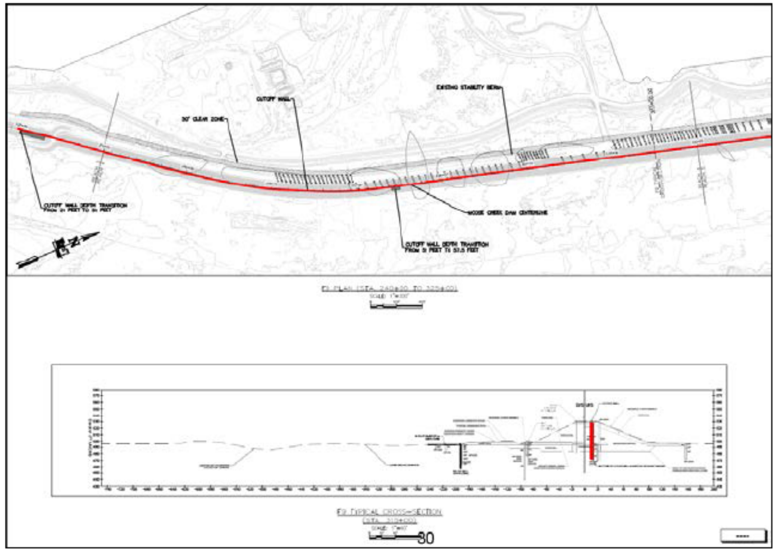
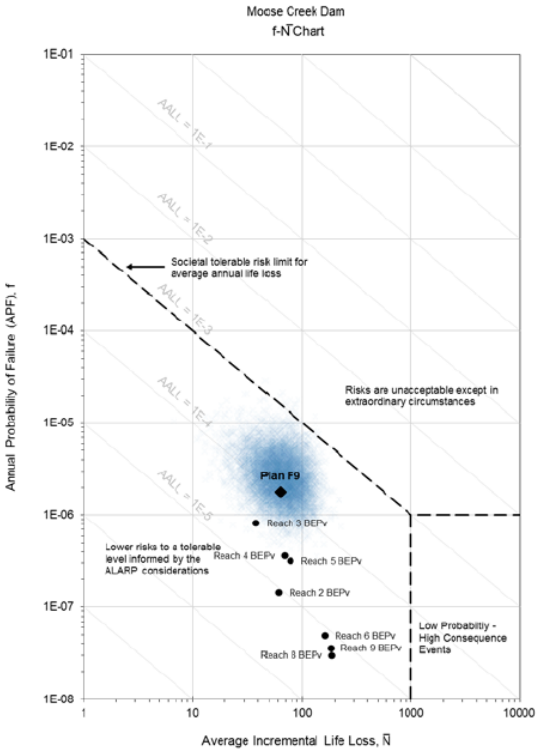
## Plan F9:

- Centerline Cutoff Wall: Reaches 4, 5, 6, 8, 9
- APF (FWAC): 2.37E-05 / APF (F9): 1.76E-06
- AALL (FWAC): 5.84E-06 / AALL (F9): 1.11E-04
- Less costly than Plan F10 : $102.6 million
- Cost to Save a Statistical Life, and Incremental Average Annual Life Loss versus Incremental Cost is lower than F10.
- Reduces risk around 1 order of magnitude below Tolerable Risk Guidelines.
- Addresses Flaw (biggest risk driver). The Cutoff Wall will interrupt and discontinue the flaw.
- More Efficient than F10.
- Minimal environmental impacts.
- Meets Planning Objectives (TRG) with High Level of certainty.
- Less uncertainty with untested embankment performance.






**Uncertainty Without Considering Intervention**

| | APF | AALL | N̄ |
|---|---|---|---|
| Upper Limit | 2.87E-05 | 1.63E-03 | 226 |
| Expected Value | 1.76E-06 | 1.11E-04 | 63 |
| Lower Limit | 3.57E-07 | 1.56E-05 | 7 |

Simulation Summary

| | |
|---|---|
| 0.22% | Above Tolerable Risk Guidelines |
| 99.78% | Below Tolerable Risk Guidelines |
| 0.00% | Low Probability - High Consequence |

# MOOSE CREEK DAM - HEAVE

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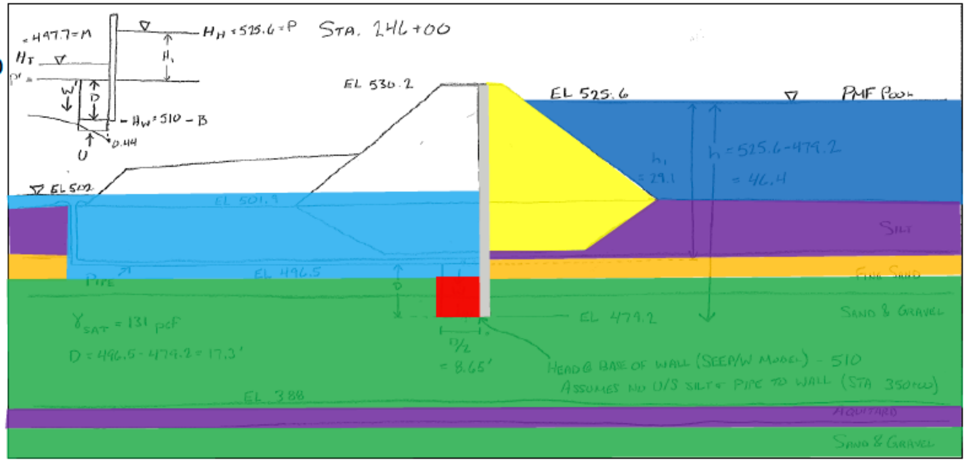
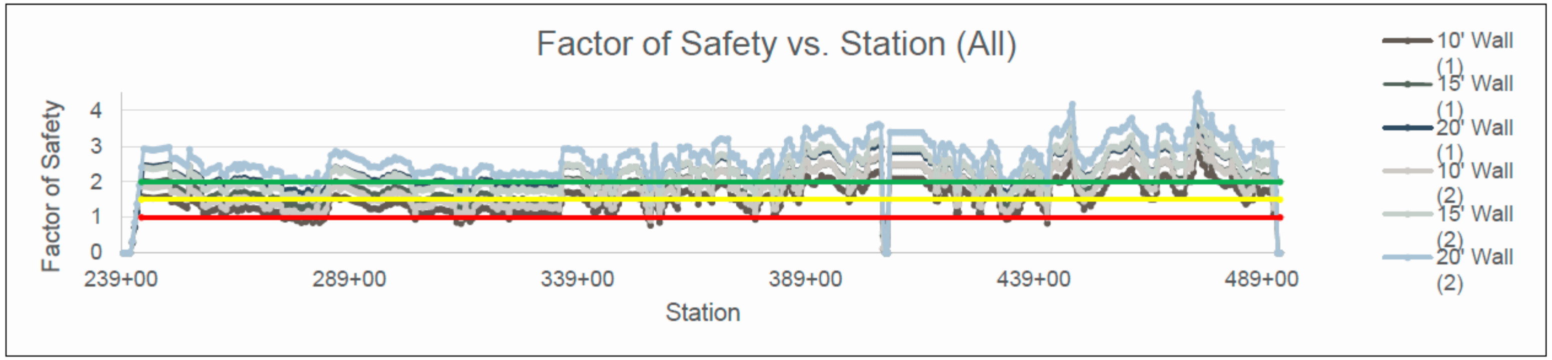
- Calculations used to prevent heave of coarse grained soil into a pipe at the bottom of the flaw material.
- Conservative, assumes there is no embankment or foundation material downstream of wall to exit.




## Results

- Wall 10 feet below flaw had an unacceptable factor of safety below 1.
- 15 foot wall had no factor of safety below 1.
- Reach 3 transition from 21 feet to initial depth of 56 feet has a low factor of safety.
- Control Works shows inaccurate factor of safety due to excavation.

| Station | Heave Calculation with Gradient Factor | | | Heave Calculation with Gradient Factor | | |
|---|---|---|---|---|---|---|
| | Foundation Material Sat Unit Weight (pcf) | | | Foundation Material Sat Unit Weight (pcf) | | |
| | 120 | 120 | 120 | 131 | 131 | 131 |
| | Gradient Factor | | | Gradient Factor | | |
| | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 |
| | 10' Wall (1) Factor of Safety | 15' Wall (1) Factor of Safety | 20' Wall (1) Factor of Safety | 10' Wall (2) Factor of Safety | 15' Wall (2) Factor of Safety | 20' Wall (2) Factor of Safety |
| Min | 0.1 | 0.3 | 0.3 | 0.1 | 0.3 | 0.3 |
| Max | 2.8 | 3.3 | 3.8 | 3.4 | 3.9 | 4.5 |
| # <1.0 | 37 | 3 | 3 | 6 | 3 | 2 |
| # <1.5 | 251 | 90 | 4 | 165 | 12 | 4 |
| # <2.0 | 425 | 307 | 142 | 341 | 172 | 16 |
| Total | 500 | 500 | 500 | 500 | 500 | 500 |



# MOOSE CREEK DAM – RISK REDUCTION

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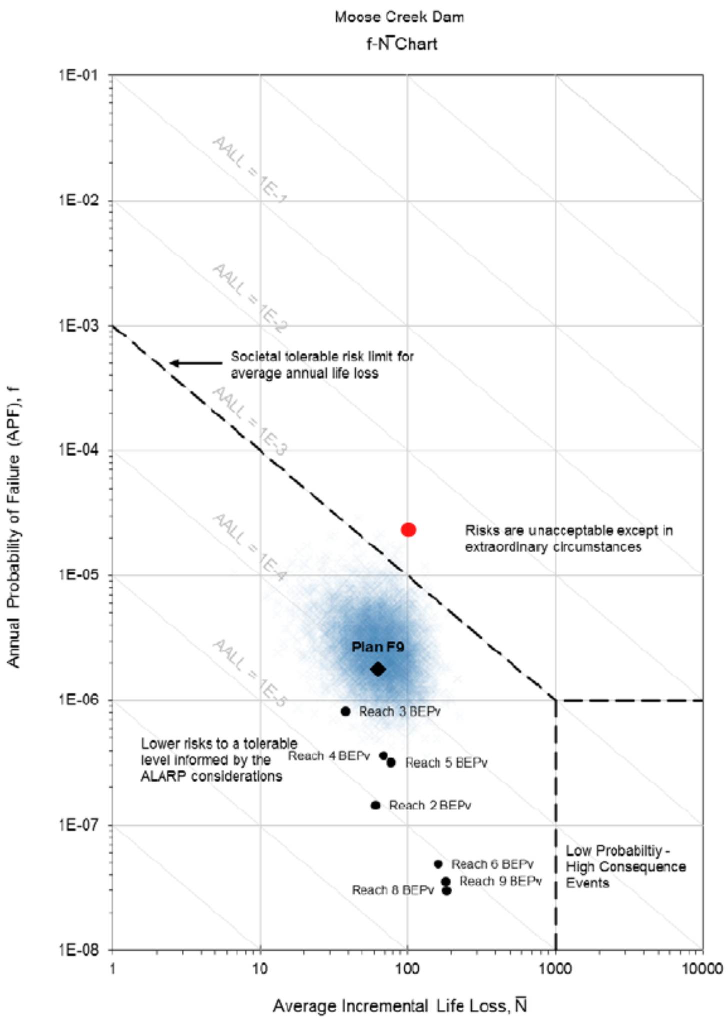
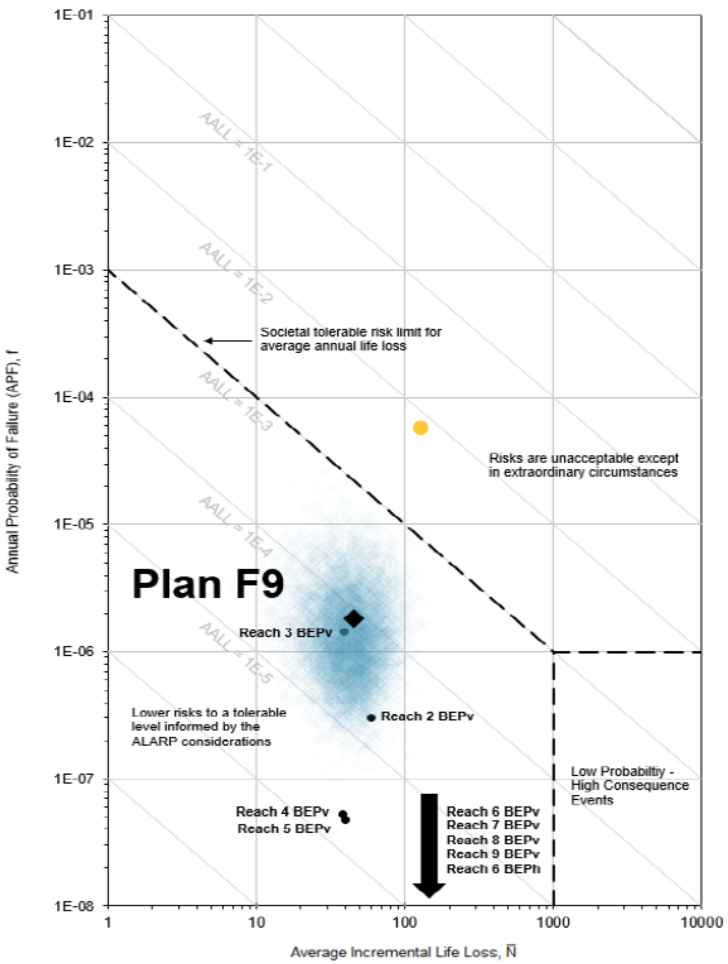
## Plan F9 (Jan 2017)




## Plan F9 (Jan 2018)



# HERBERT HOOVER DIKE

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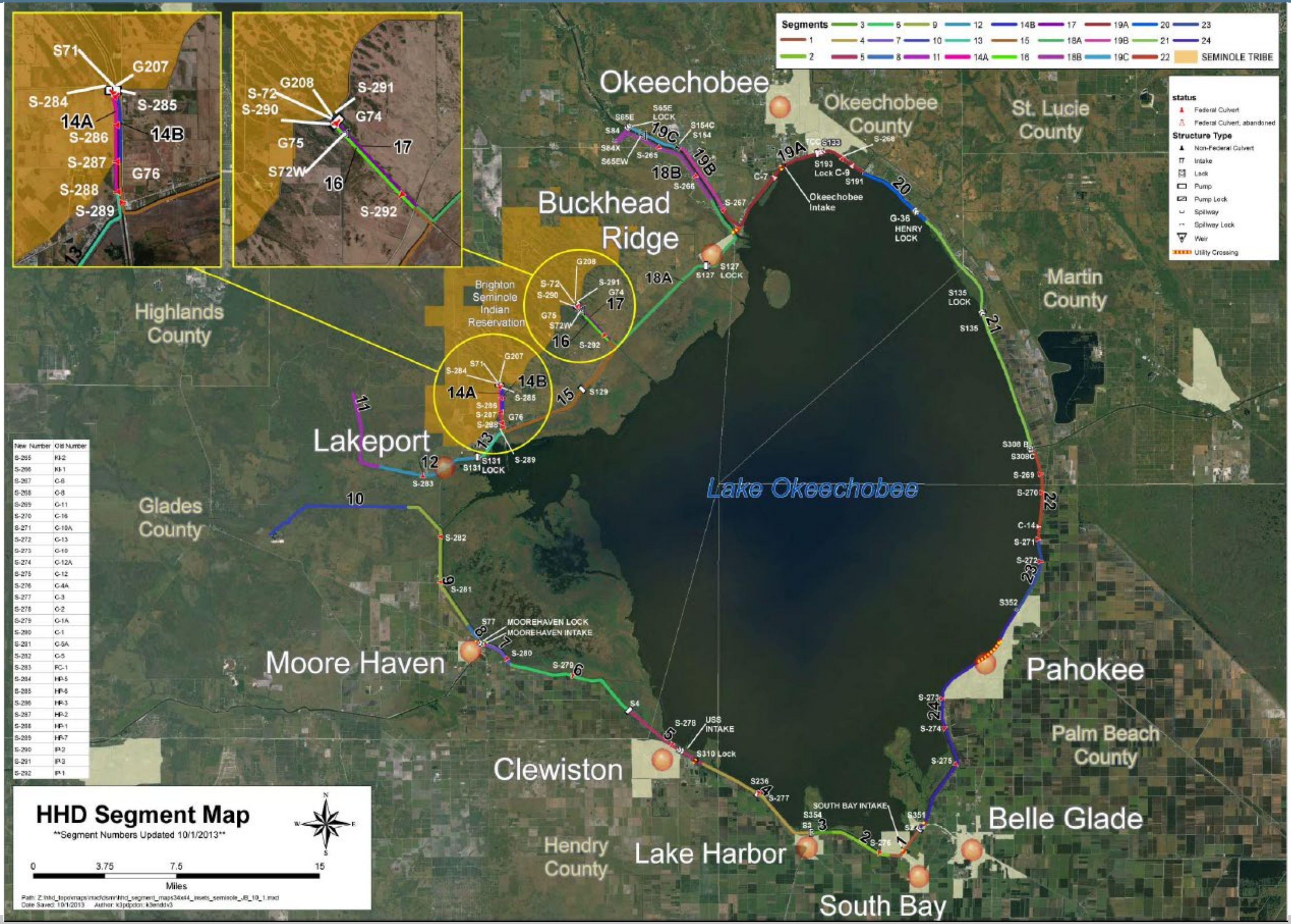

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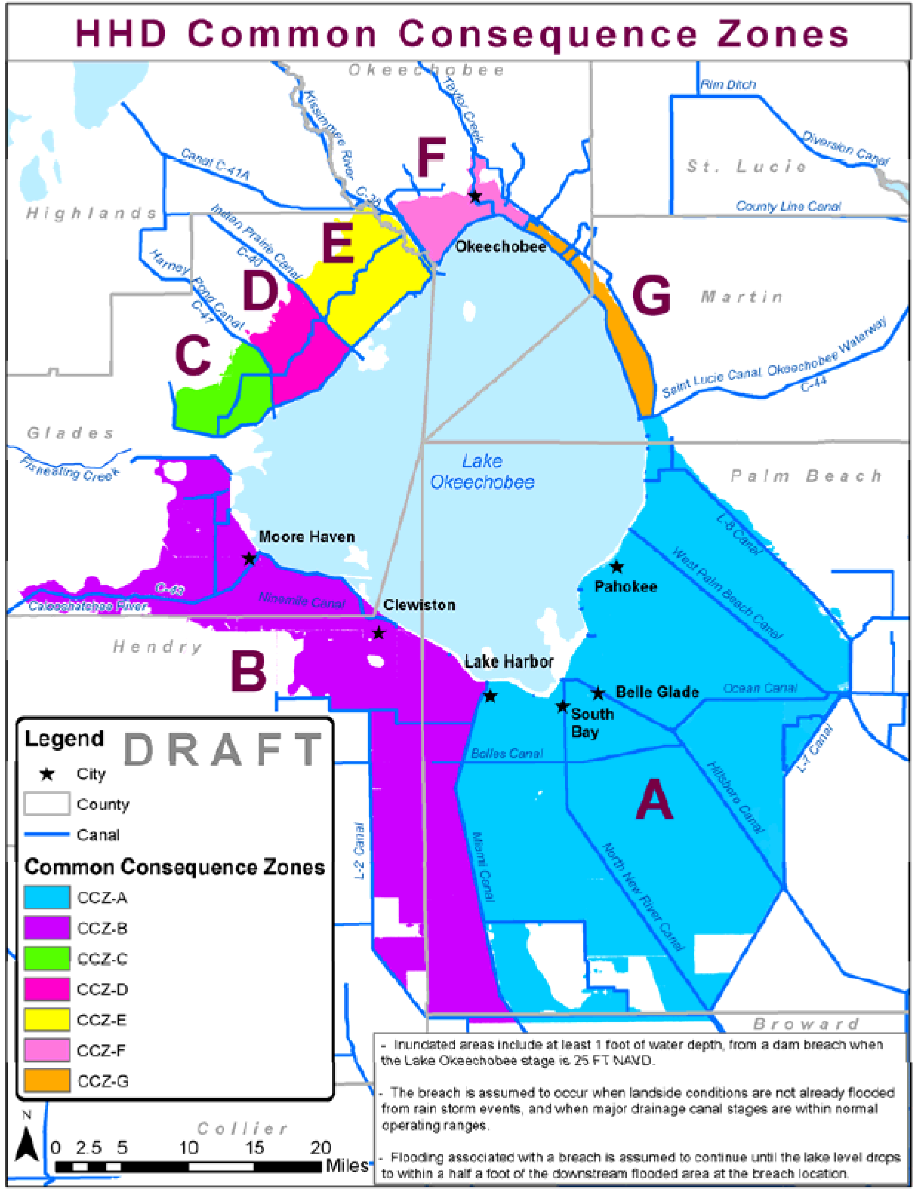

# HERBERT HOOVER DIKE – BACKGROUND

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- 2001 – 2005
  - ✓ Did not meet exit gradient design criteria
  - ✓ Designs formulated to meet criteria
  - ✓ Cutoff wall through CIZ A – 200’/65 m deep
  - ✓ ~$10M/mile = $2.5 Billion
- 2006 – New Guidance
  - ✓ Evaluate Risk
  - ✓ Formulate 2 alternatives
  - ✓ 1 – Just to tolerable levels
  - ✓ 2 – Tolerable levels + 1 order of magnitude

# HERBERT HOOVER DIKE – FAILURE MODE

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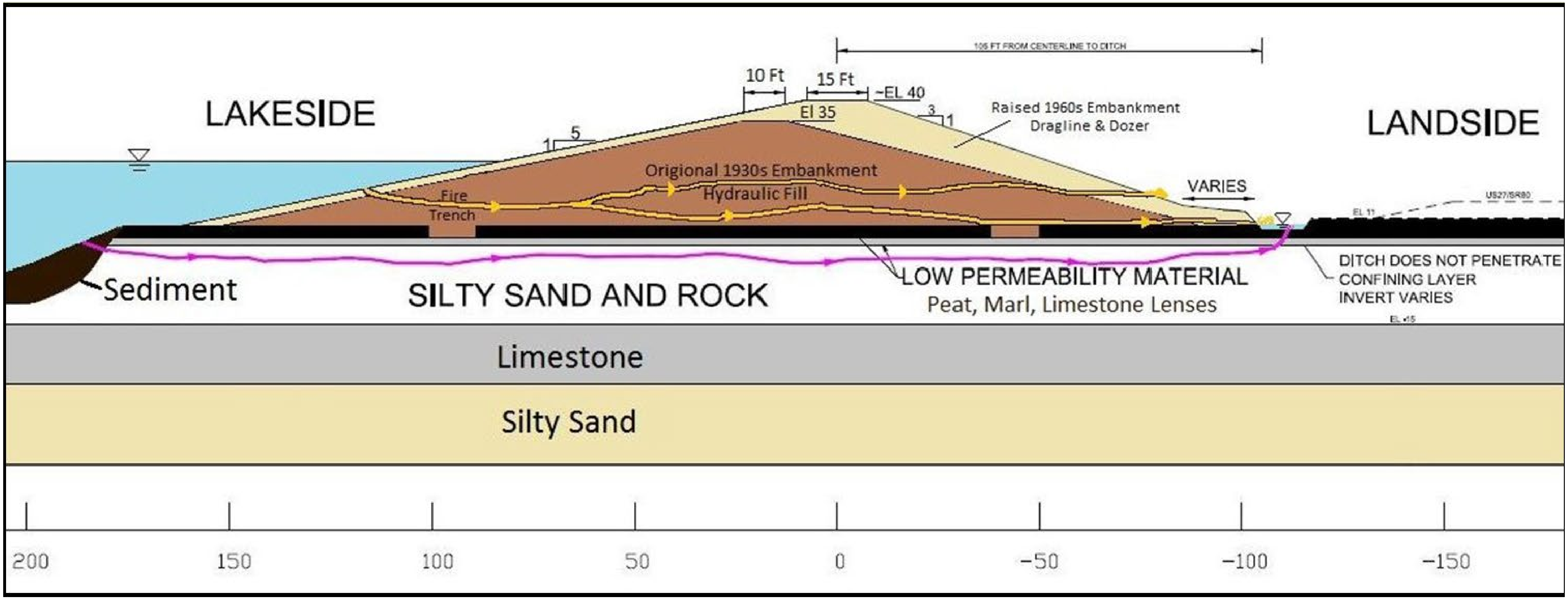

# HERBERT HOOVER DIKE – ALTERNATIVES

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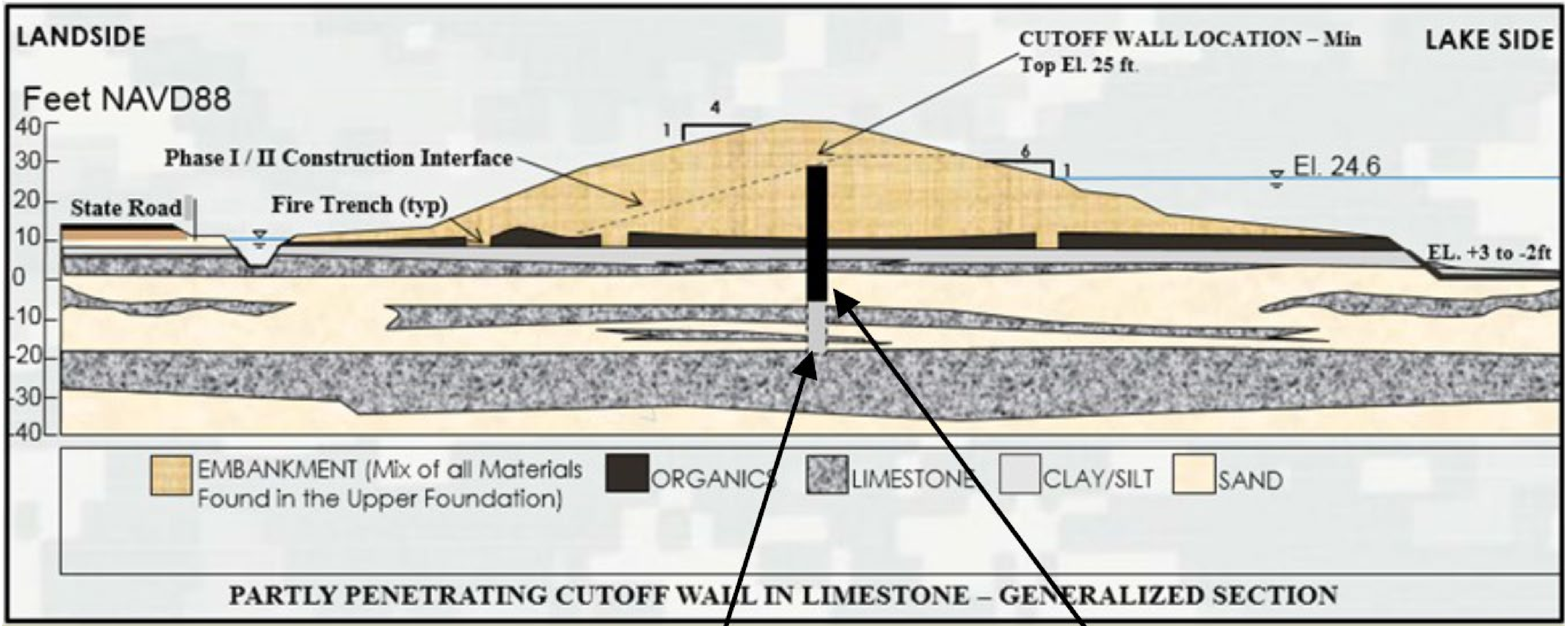


ALARP Design

Minimum Design

# HERBERT HOOVER DIKE – EVALUATION



| | Existing Condition(3) | FWAC/IRRM Permanent(3) | Alternative 1 (Societal Life Safety ) | Alternative 2 (Societal, Individual and APF) | Alternative 3 (Societal, and APF with significant consequences) | Alternative 4 (Societal, Individual, APF and Essential Guidelines) |
|---|---|---|---|---|---|---|
| Segments Remediated | No Action | | 5-2 and 8 | 4 - 9 | 4 - 9 (southern) | 4 - 9 |
| Solution | | | Cutoff-Wall | Cutoff-Wall | Cutoff-Wall | Internal Drainage System |
| **Project Performance** | | | | | | |
| Residual Annualized Probability of Failure (APF) | 3.78E-03 | 3.78E-03 | 3.78E-03 | 1.10E-04 | 2.01E-04 | 8.34E-05 |
| Residual Annualized Life Loss (ALL) | 1.01E-03 | 1.66E-04 | 1.02E-04 | 6.05E-05 | 6.05E-05 | 5.95E-05 |
| Individual Tolerable Risk | 0.00238 | 0.00238 | 2.38E-03 | 6.78E-05 | 1.27E-04 | 5.01E-05 |
| **Costs** | | | | | | |
| Total Estimated Construction Cost | $0 | $0 | $16,200,000 | $345,000,000 | $293,400,000 | $660,900,000 |
| Change in Annual O&M | $0 | $0 | $0 | $0 | $0 | $100,000 |
| Annual Cost | $0 | $0 | $530,000 | $11,300,000 | $9,610,000 | $21,750,000 |
| **Economic Impacts of a Breach** | | | | | | |
| Direct Economic Impacts 31ft | $2,415,764,000 | | | | | |
| Direct Economic Impacts 25ft | $1,453,393,000 | | | | | |
| Direct Economic Impacts 20ft | $711,407,000 | | | | | |
| **Expected Annual Economic Impacts** | | | | | | |
| Annual Economic Damages | $172,000 | $172,000 | $172,000 | $5,000 | $5,000 | $4,000 |
| **Costs/Benefits Analysis** | | | | | | |
| Net Economic Cost (Change in Annual Cost - Change Economic Damages) | | | $530,000 | $11,133,000 | $9,443,000 | $21,582,000 |
| Benefit Cost Ratio (BCR) | | | 0.00 | 0.01 | 0.02 | 0.01 |
| CSSL (Net Cost/Change in CSSL) | | | $8,280,000,000 | $105,530,000,000 | $89,510,000,000 | $202,650,000,000 |

# HERBERT HOOVER DIKE - EVALUATION

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| CIZ | Segment | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|---|---|---|---|---|---|
| Solution | | Cutoff-Wall | Cutoff-Wall | Cutoff-Wall | Pumped Internal Drainage System |
| | 4 | No Action | $83,100,000 | $83,100,000 | $158,700,000 |
| | 5-2 | $1,500,000 | $16,800,000 | $16,800,000 | $30,900,000 |
| | 5 | No Action | $41,600,000 | $41,600,000 | $75,200,000 |
| | 6 | No Action | $86,400,000 | $86,400,000 | $157,700,000 |
| | 7 | No Action | $22,400,000 | $22,400,000 | $41,200,000 |
| | 8 | $14,700,000 | $14,700,000 | $14,700,000 | $28,800,000 |
| CIZ B | 9 | No Action | $80,200,000 | $28,400,000 | $168,400,000 |
| | 12 | $30,000,000 | $63,000,000 | $30,000,000 | $108,200,000 |
| CIZ C | 13 | $1,500,000 | $11,700,000 | $1,500,000 | $23,000,000 |
| Totals (ALARP Depth) | | $47,700,000 | $419,900,000 | $324,900,000 | $792,100,000 |
| Cost increase 15 to 20% | | | | | |
| Totals (Minimal Design Depth) | | $47,700,000 | $361,700,000 | $280,700,000 | $823,784,000 |

Keys:

- CIZ D-G dropped out
- $300M vs $2.5B
- Met individual and societal risk
- ALARP to account for uncertainty
- Does not meet design standards for exit gradient


# Questions?