7th Annual Technical Forum Geohazards In Transportation In The Appalachian Region

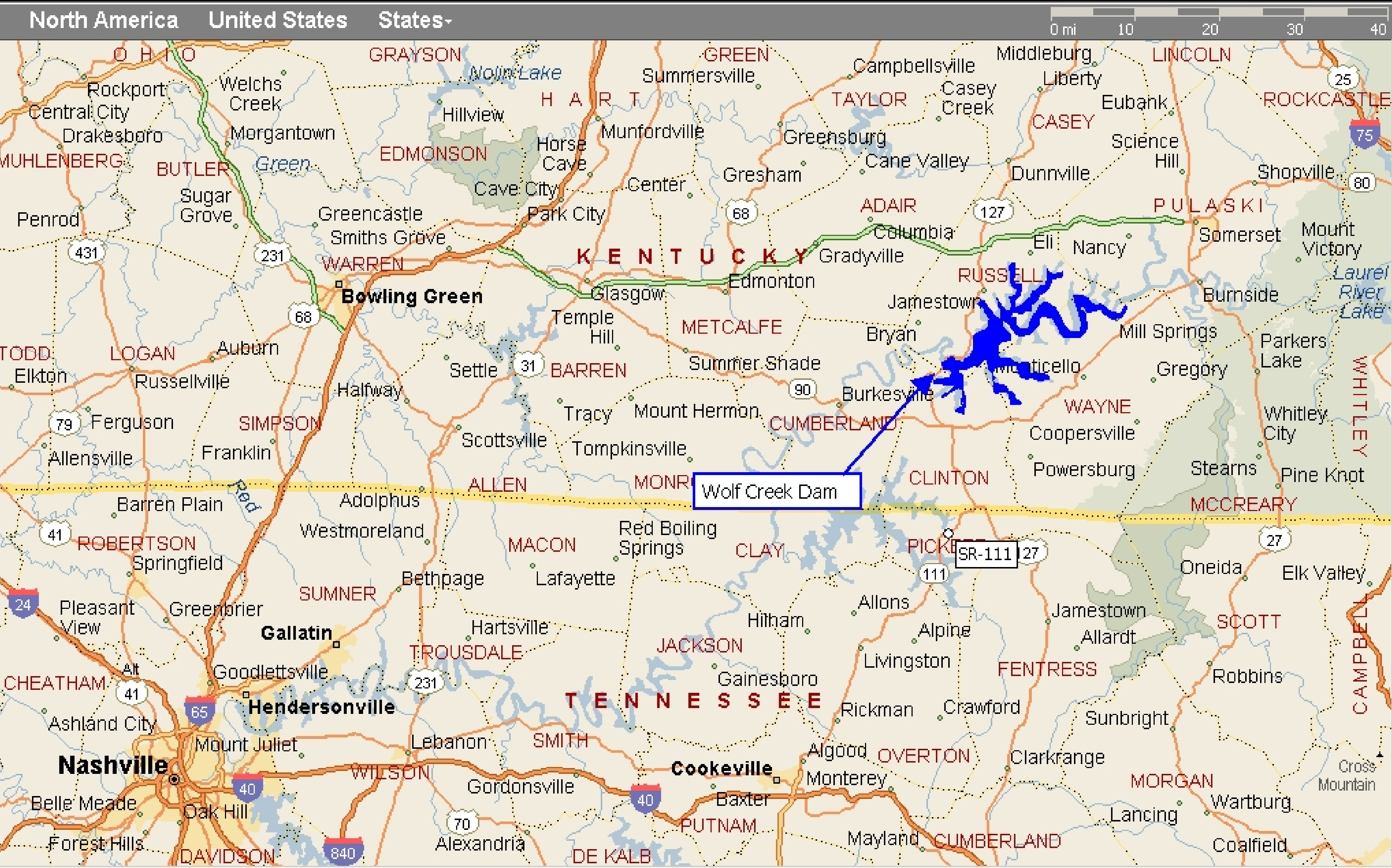
Session 4 Economic Impacts of a Karst Foundation Wolf Creek Dam,

US Army Corps of Engineers, Nashville District

Outline of Topics

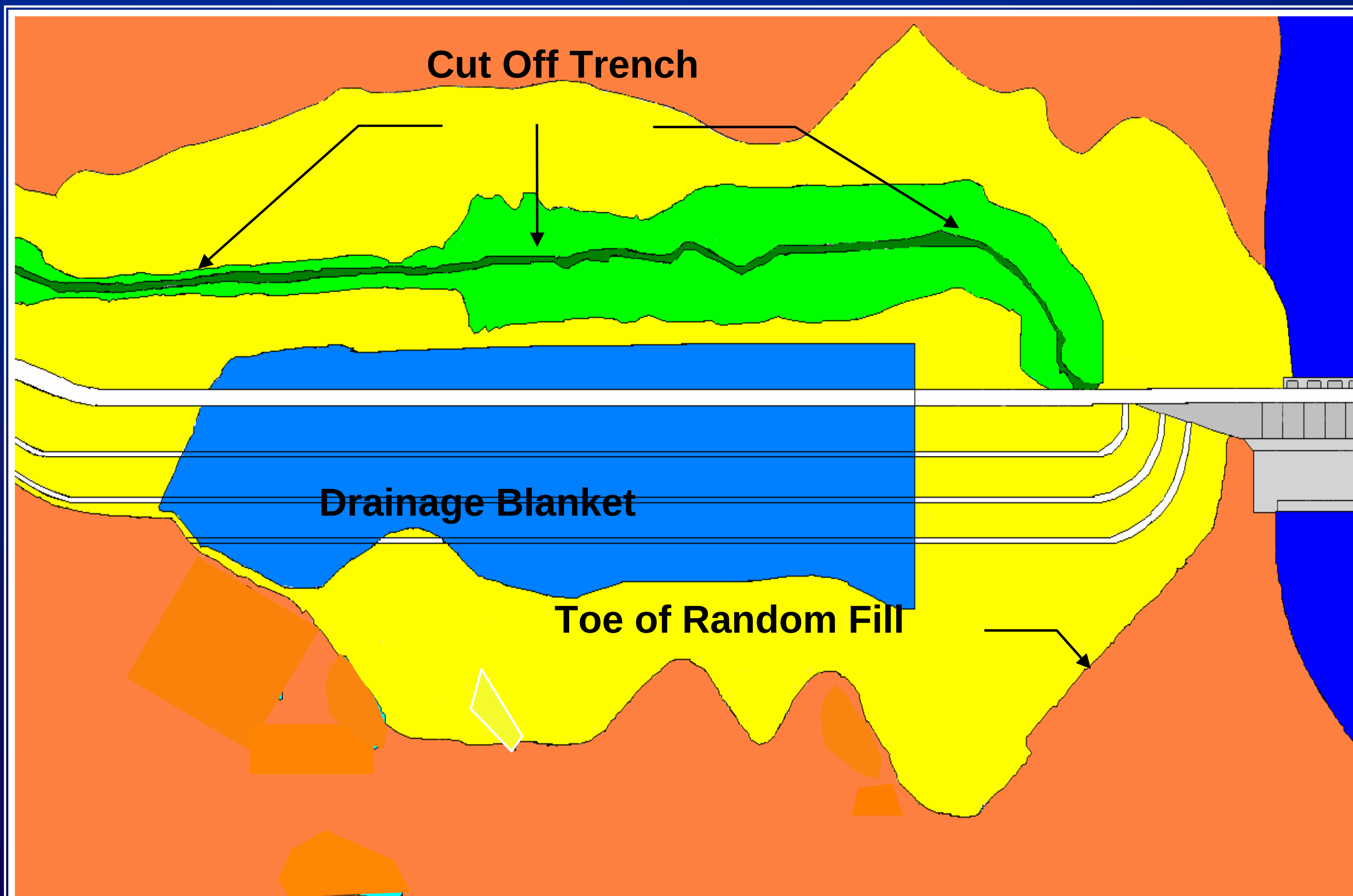
- Project Description.
- General Background.
- Reliability Studies.
- Interim Risk Reduction Measures.
- Operating Restrictions.
- Economic Impacts.

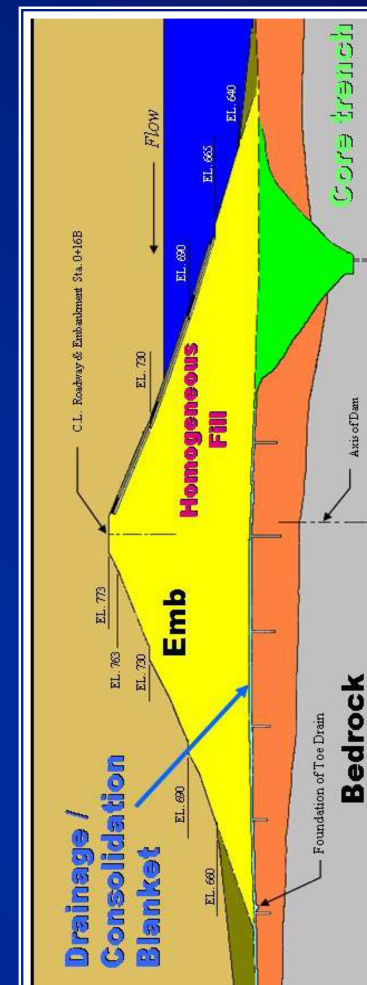
Project Location



Project Features

EMBANKMENT PLAN AND SECTION



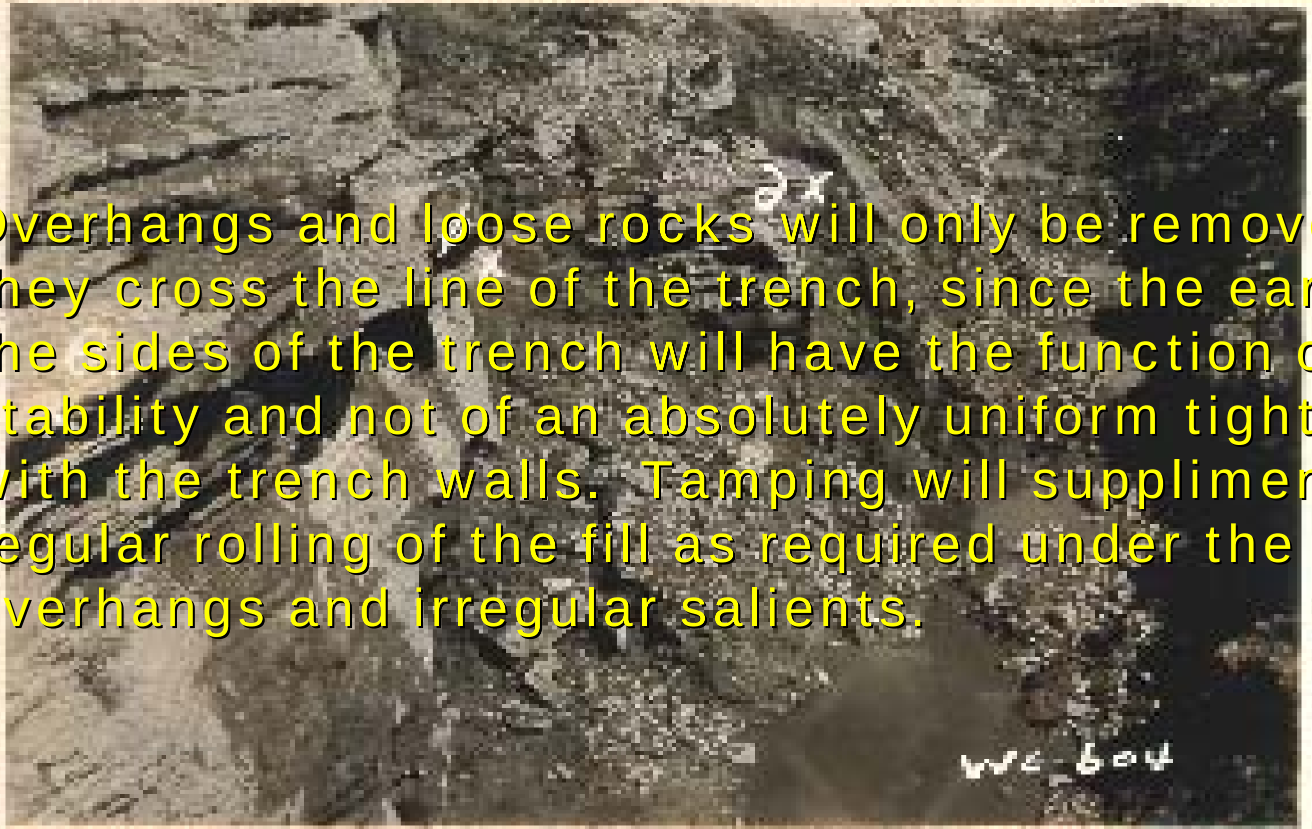


Foundation Treatment Problems

- Treatment techniques were inadequate for this geology
- Most of the alluvium left in place
- Except for cut-off trench, no embankment foundation treatment
- Cutoff trench design and construction inadequate

I-A, -B, and -E. The bottom of this section of trench, at this stage of excavation, is still in overburden except for a few narrow areas where the rock salients showing in the overburden slopes were connected across the trench line. It is proposed to excavate the floor of the trench to continuous sound rock for the grout curtain. • Overhangs and loose rock

Overhangs and loose rocks will only be removed where they cross the line of the trench, since the earthfill in the sides of the trench will have the function only of stability and not of an absolutely uniform tight contact with the trench walls. Tamping will suppliment the regular rolling of the fill as required under the overhangs and irregular salients.



8-27-42. Section 3E in trench from sta. 54+50.

I-E

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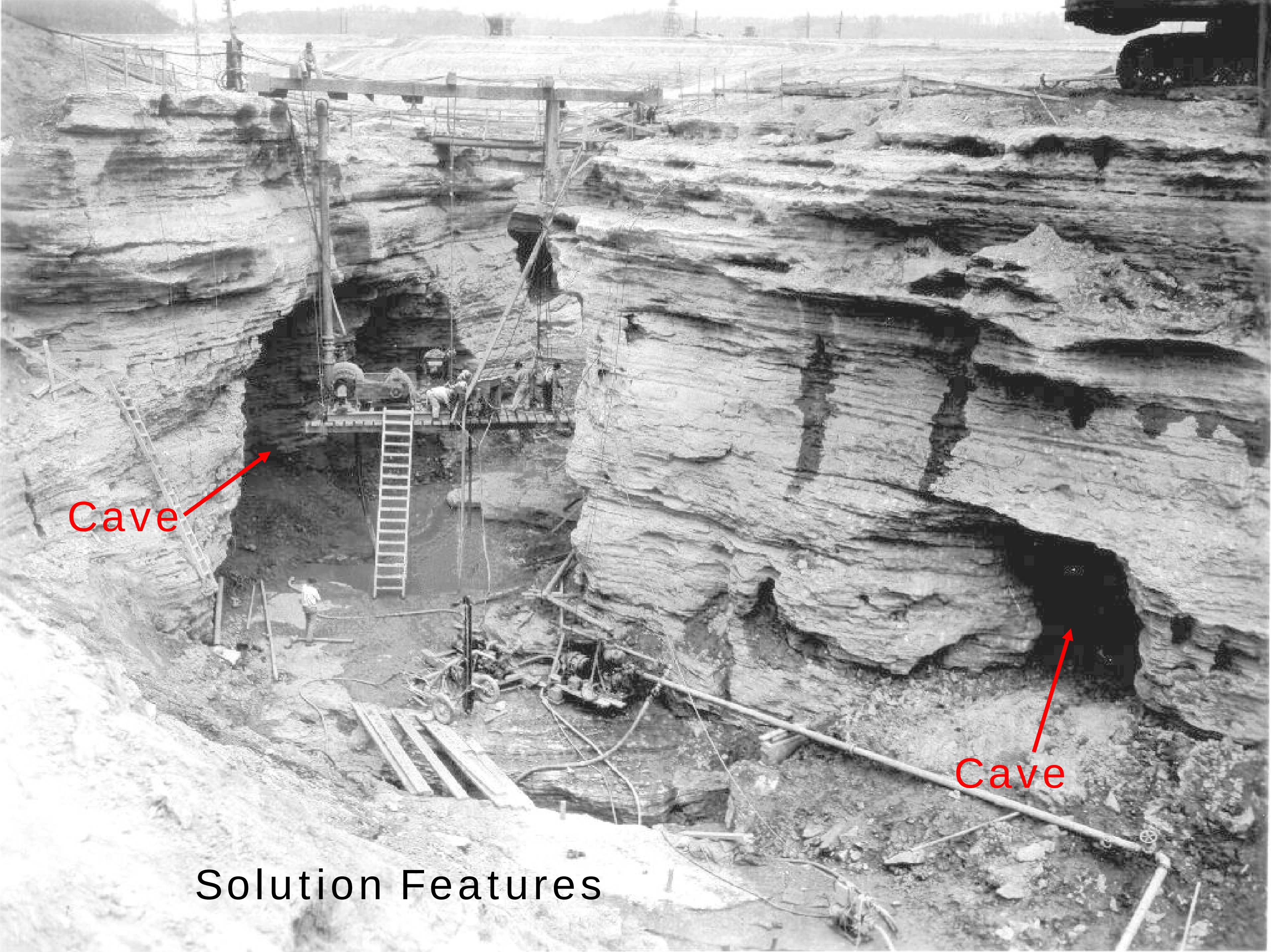
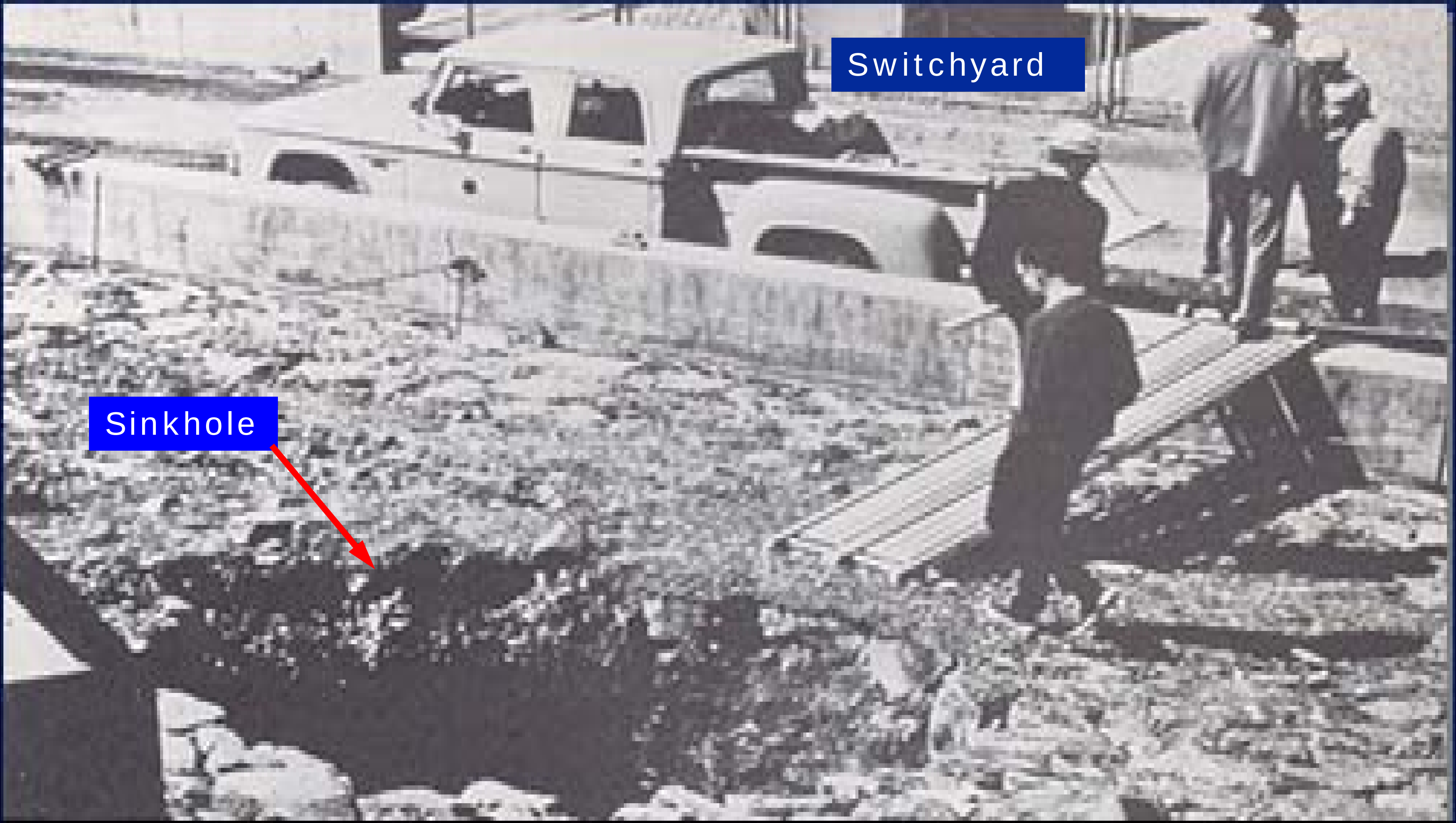
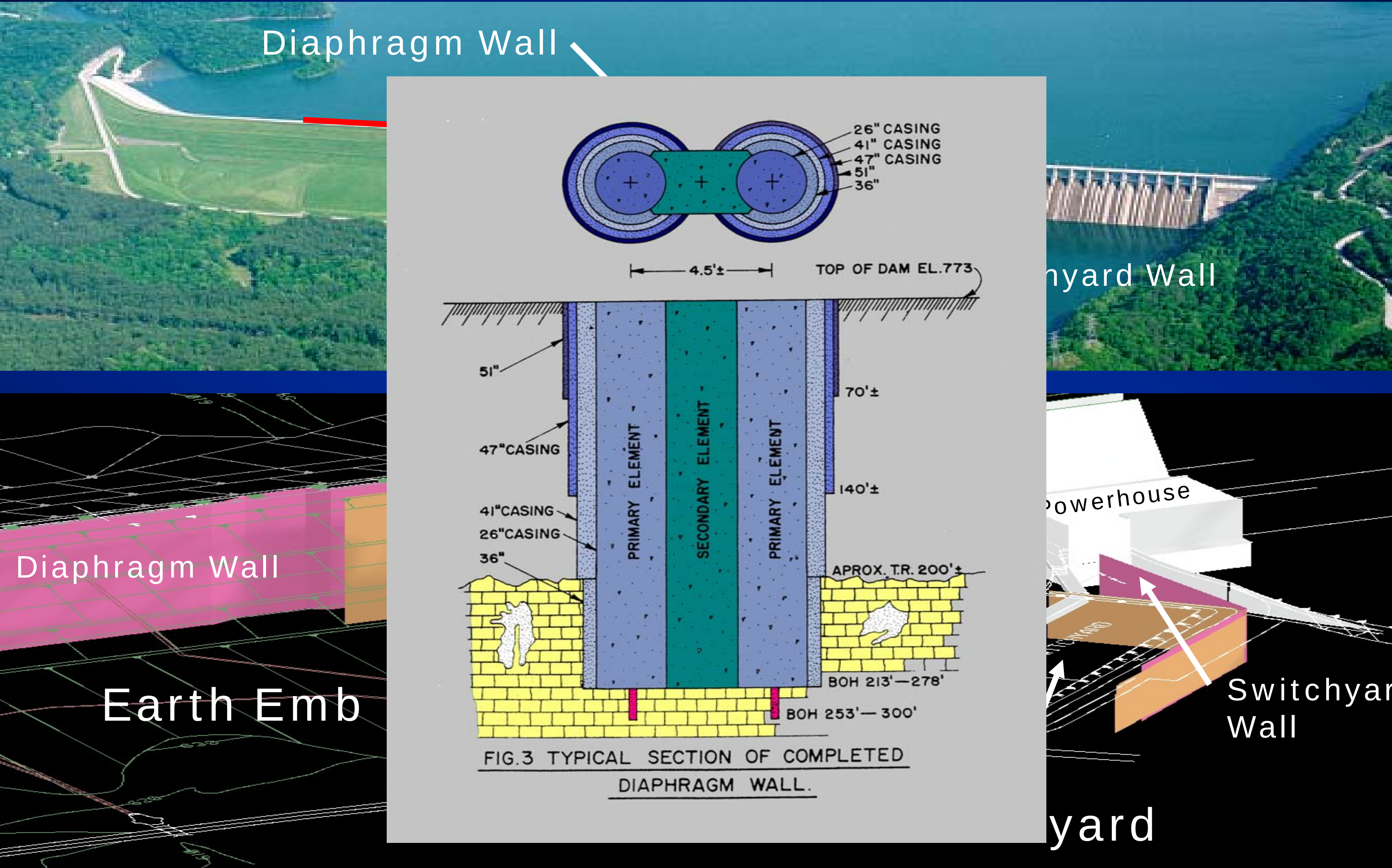


Solution Features

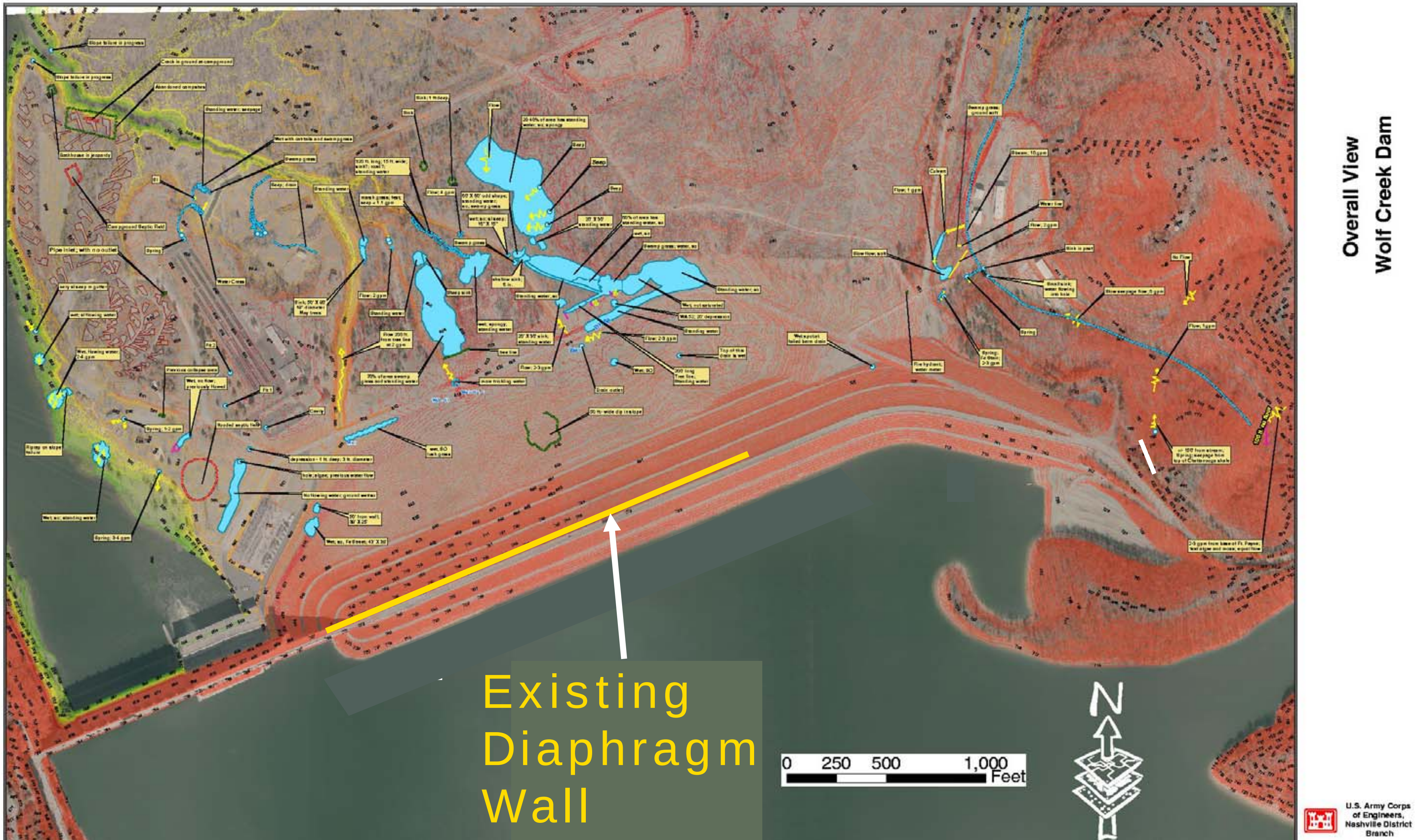
1968 Sinkhole



1960's and 70's Remedial Features



Post Wall Performance – Wet Areas March 2004



Risk

- Risk is defined as the probability of unsatisfactory performance times the consequences of the unsatisfactory performance.
- For Wolf Creek, based on a breach of the dam the estimated consequences are up to 350 lives lost and over $3 billion in damages.
- **How do we establish the probability of unsatisfactory performance?**
- **It is especially difficult to predict the behavior in Karst.**

Reliability Analysis for Dams and Levees

Excerpts from a presentation by

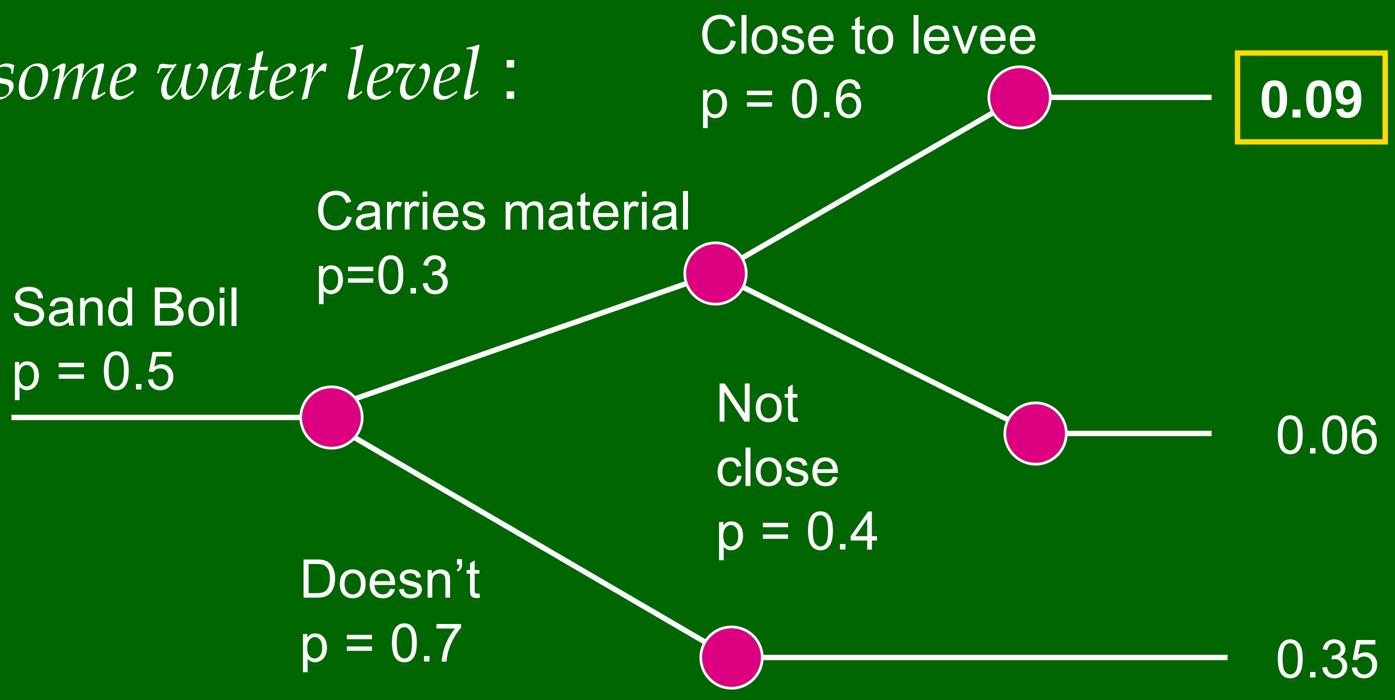
Thomas F. Wolff, Ph.D., P.E.
Michigan State University

Grand Rapids Branch ASCE
September 2002

MICHIGAN STATE
UNIVERSITY

General Approaches: Event Tree

given some water level :



Most problems of interest involve or could be represented by an event tree..

Probabilities for the Event Tree - How?????

- A) f (Uncertainty in parameter values) Reliability Index Methods (β)
  - **Monte Carlo method**
  - **FOSM methods**
    - **point estimate**
    - **Taylor's Series**
      - Mean Value
      - Hasofer-Lind
- B) Frequency Basis
  - **Exponential, Weibull, or other lifetime distribution**
- C) Judgmental Values
  - **Expert elicitation**

A) Pr(f) = Function of Parameter Uncertainty

- **Identify** performance function **and** limit state**, typically ln(FS) = 0**
- **Identify** random variables**, X_i**
- Characterize **random variables,**
  - **E[X], σ_X, ρ**
- **Determine** E[FS], σ_{FS}
- **Determine** Reliability Index, β
- **Assume Distribution and calculate**

  Pr(f) **= f(β)**

Pros and Cons of b, Pr(U)

- Advantages
  - "Plug and Chug"
  - fairly easy to understand with some training
  - provides some insight about the problem
- Disadvantages
  - Still need better practical tools for complex problems
  - Non-unique, can be seriously in error
  - No inherent time component
  - only accounts for uncertainties related to parameter values and models

B) Frequency-based Probabilities

- Represent probability of event per time period
- Poisson / exponential model well-recognized in floods and earthquakes
- Weibull model permits increasing or decreasing event rates as f(t), well developed in mechanical & electrical appliactions
- Some application in material deterioration
- Requires historical data to fit

Pros and Cons of Frequency Models

- Advantages
  - Can be checked against reality and history
  - Can obtain confidence limits on the number of events
  - Is compatible with economic analysis
- Disadvantages
  - Need historical data
  - Uncertainty in extending into future
  - Need “homogeneous” or replicate data sets
  - Ignores site-specific variations in structural condition

C) Judgmental Probabilities

- Mathematically equivalent to previous two, can be handled in same way
- Can be obtained by Expert Elicitation
  - a systematic method of quantifying individual judgments and developing some consensus, in the absence of means to quantify frequency data or parameter uncertainty

Pros and Cons of Judgmental Probabilities

- **Advantages**
  - Gives you a number when nothing else will
  - May be better reality check than parameter uncertainty approach
  - permits consideration of site-specific information
  - Some experience in application to dams
- **Disadvantages**
  - Distrusted by some (including some within Federal Agencies)
  - Some consider values "less accurate" than calculated ones
  - Non-unique values
  - Who is an expert?

1. Major Rehabilitation Report.

- **1. Analysis from Major Rehabilitation Report (MRR)**
  - Based on analysis of stress indicators
  - Limit State defined as condition that would require operational restrictions. Limit State threshold selected by expert elicitation.
  - Damage accumulation based on projection of instrumentation data coupled with historical pool stages using a Monte Carlo simulation.
  - Reviewed by an independent panel of experts
  - Stress indicators show gradual change from 1984 to present
  - Considered risk to be high
  - Analysis based on engineering judgment

2. Screening Portfolio Risk Assessment

- **2. Screening Portfolio Risk Assessment**
  - In-house Corps expertise
  - Reviewed MRR and other data
  - Purpose to determine ranking in severity of Corps dams
  - Placed Wolf Creek in the “Urgent and Compelling” category

3. Independent Peer Review Panel

- 3. Independent Peer Review Panel
  - Independent Consultants
  - Purpose to validate the SPRA process and review projects in the "Urgent and Compelling" category
  - Recommended immediate operating restrictions at Wolf Creek
  - Considered risk to be high
  - Analysis based on engineering judgment

Reliability Results

- All three studies conclude the project is deficient.
- Immediate measures should be taken to reduce the risk.
- Some of them can be implemented without serious negative impact.

Risk Reduction Actions

Interim Risk Mitigation Measures

- Dam Safety Program
- Monitoring 24/7
- Increased instrumentation
- Enhanced and aggressive EAP process
- Public Meetings
- Independent Expert Panel
- Stockpiling material

Risk Reduction Actions

- **Trigger Events that Would Require Emergency Drawdown**
  - **Significant abnormal instrumentation readings**
  - **Sinkholes or settlement in the dam**
  - **Muddy flows**
  - **Slide in the dam slope**

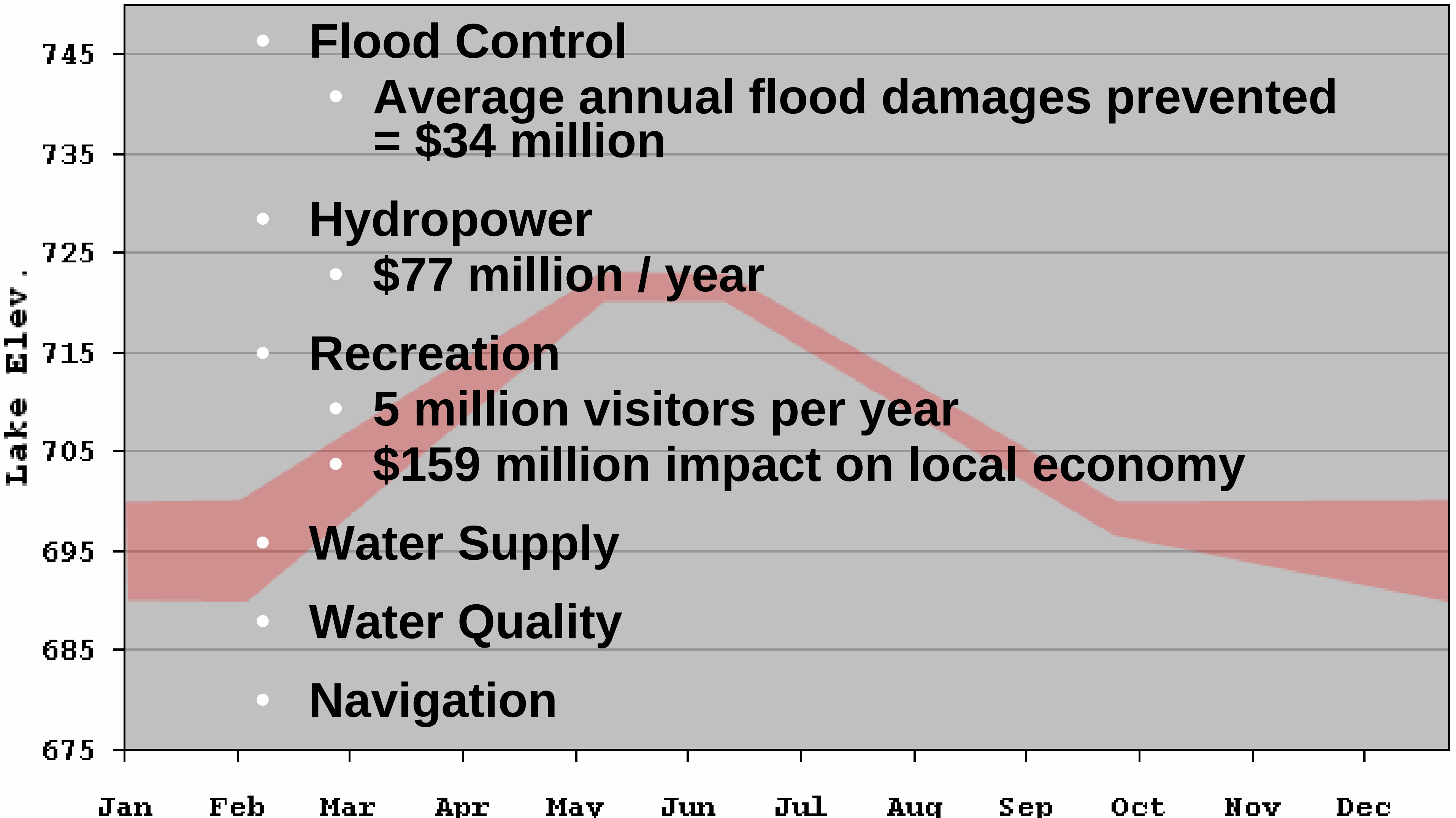
- **Modified Lake Level Operation**

Operating Restrictions
Lower the Lake = Lower the Risk

- This decision comes with a cost.
- The benefits derived from the project diminish as the lake is lowered.
- How do you make the decision which balances lowered risk with lost benefits.

Project Benefits And Lake Level Target Zone

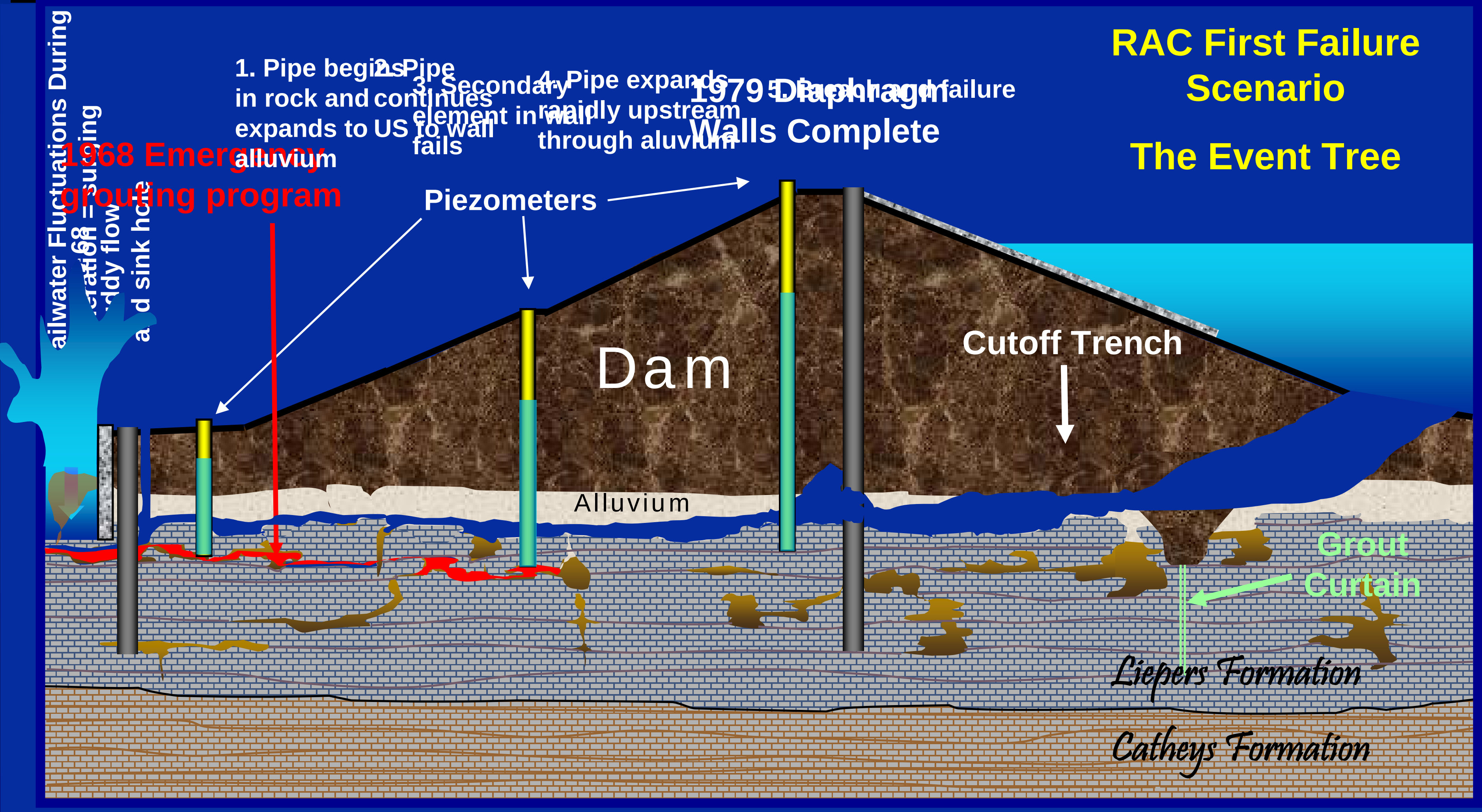
- Flood Control
  - Average annual flood damages prevented = $34 million
- Hydropower
  - $77 million / year
- Recreation
  - 5 million visitors per year
  - $159 million impact on local economy
- Water Supply
- Water Quality
- Navigation



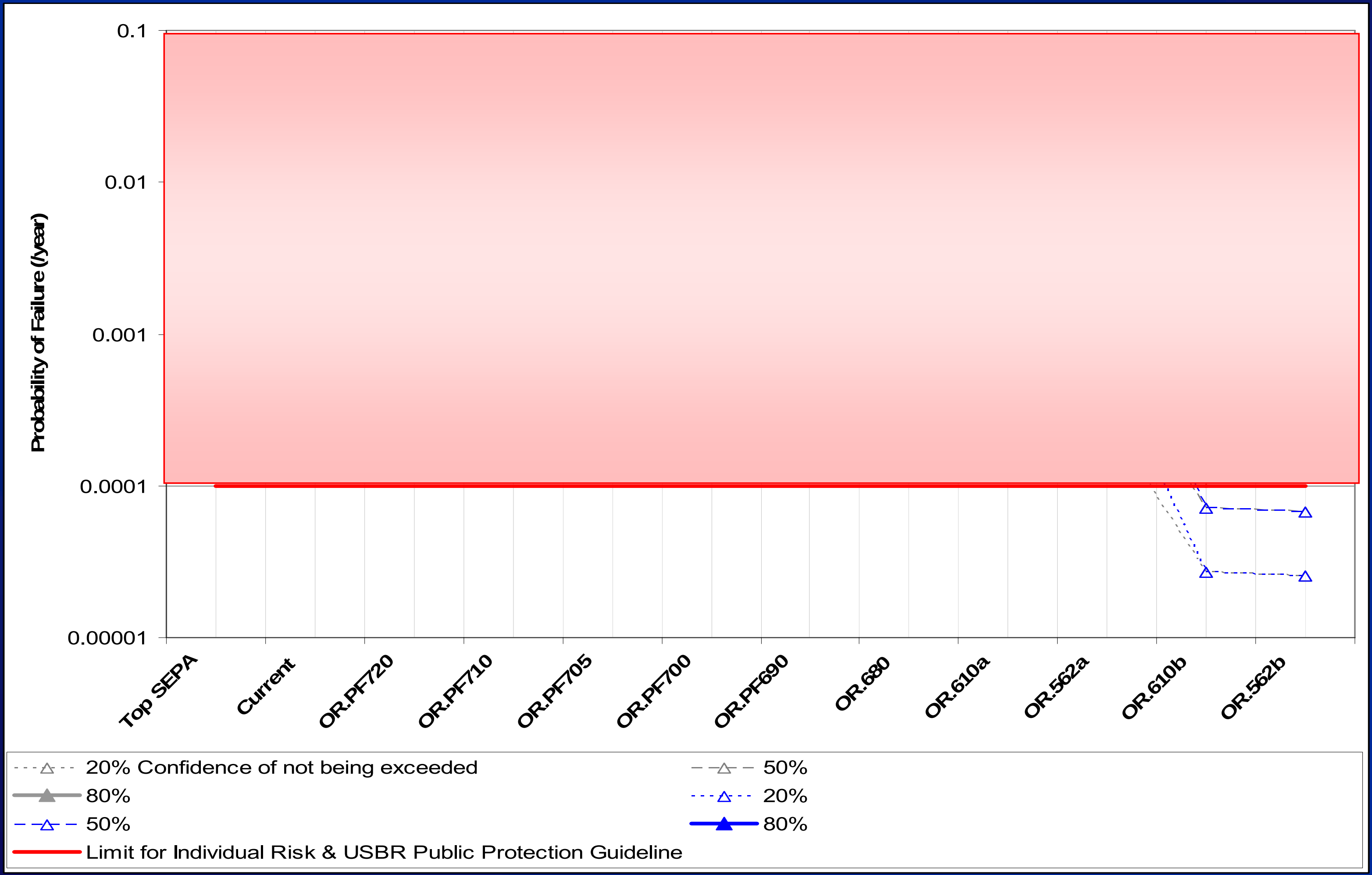
4. Probability of Failure/ Operational Restrictions

- 4. RAC Engineers and Economists Study (Operating Restrictions) Utah State U. Initiated before Peer Group.
  – Used risk assessment methodology to determine effect on risk of various operating restrictions
  – Preliminary ‘bounding analysis’ showed unacceptable level of risk
  – Uses process similar to ‘expert elicitation’ to quantify engineering judgment

Wolf Creek Dam Section Damage Progression



Annualized Probability of Failure



What Does This Mean?

- None of the operating restriction meet the criteria for tolerable risk except those that require structural modification of project.
- These restrictions result in loss of annual benefits totaling $200 million.
- There are severe environmental consequences to these restrictions.
- Unforeseen consequences?

Where Are We Now

- Decision based on previous risk studies + impacts that result and health and safety concerns for upstream residents. (Water Intakes). Corporate decision not solely District jurisdiction.
- Operate the pool at 680 – flat.
- Incremental approach. If distress indicators improve and grouting proceeds, evaluate new operating level. If not, consider more severe restrictions.

Thomas F. Wolff, Ph.D., P.E.
Michigan State University

"How accurately can Pr(f) be calculated?"

- Not very accurately **(my opinion) -- Many ill-defined links in process:**
  - variations in deterministic and probabilistic models
  - different methods of characterizing soil parameters
  - ϕ - c strength envelopes are difficult
  - slope is a system of slip surfaces
  - distributions of permeability and permeability ratio
  - difficult to quantify spatial correlation in practice
  - difficult to account for length of embankments
  - difficult to account for independence vs correlation of multiple monoliths, multiple footings, etc.

Construction Costs

- First Emergency Grouting $15 million
- Composite Cut Off Wall $ 90 million
- Current Emergency Grouting $50 million
- Future Cut Off Wall $250 million ±

Impact Costs

- Lost hydropower generation = $70 million
- Cost of extending launching ramps = $ 165K
- Cost of extending water intakes = $ several million
- Lost revenue from recreation = $65 million
- Fish hatchery modifications $750K +
- Others

Questions