Risk-Informed Decision Making to Prioritize Rehabilitation of South Carolina's High Hazard Potential Dams

National Dam Safety Program Technical Seminar | February 13 & 14

FEMA

CDM Smith®

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A special thank you to...

John M. McCain Jr., SC DHEC Dam Safety Section Manager
Calvin Barefoot, USACE, PFMA Facilitator
Dr. Jonathan Quebbeman and Research Triangle Institute staff
Participation and input from dam owners and representatives

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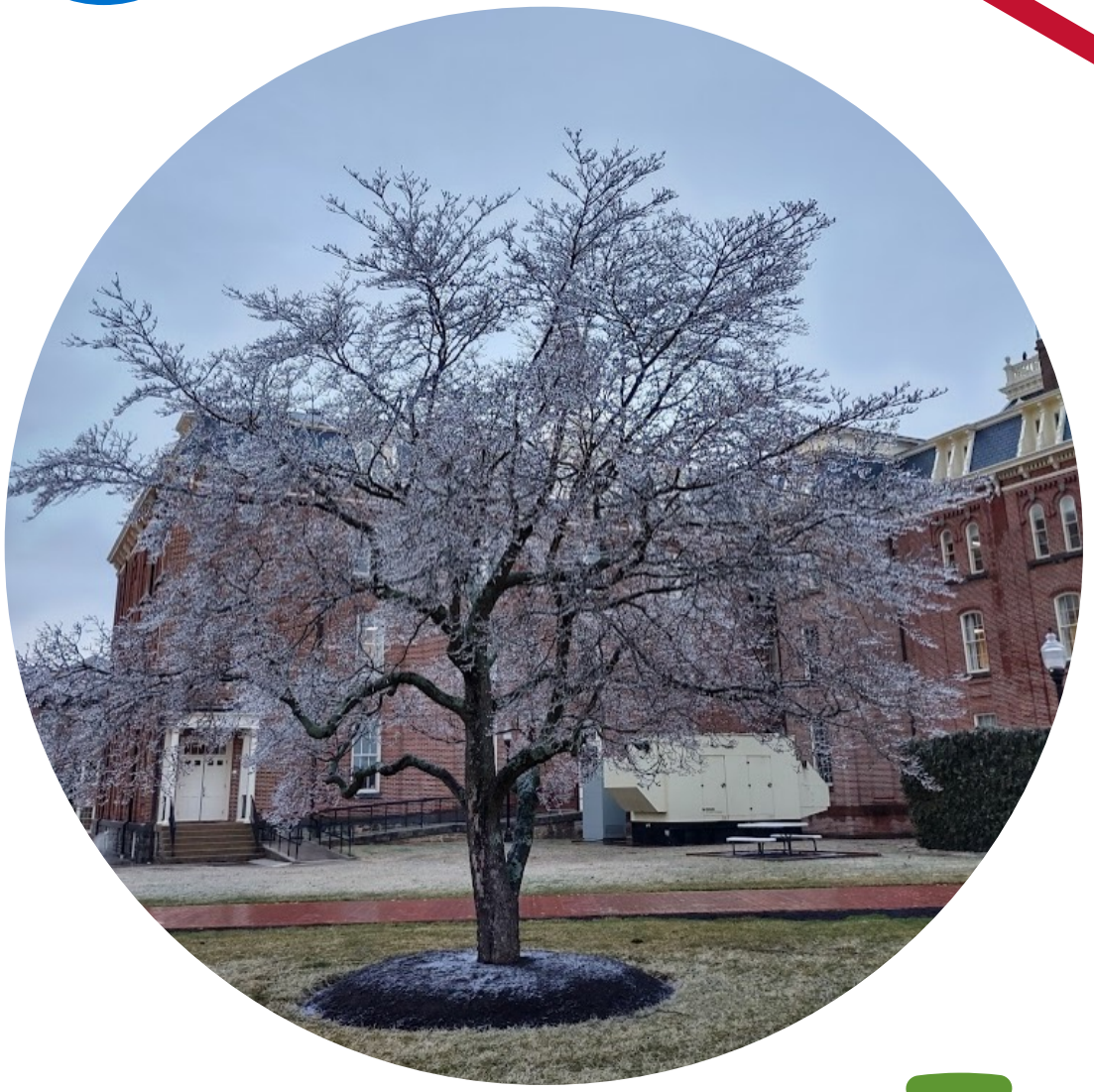


Happy Valentine's Day!

Call your loved one!

Agenda

- FY19 HHPD Scope and Purpose
- Prioritization of Dams for FEMA HHPD SQRA
- Further Analyses and Information Gathering for SQRA
- PFMA Workshops
- SQRA Results and Recommendations
- Lessons Learned and Key Takeaways

FY19 HHPD Scope and Purpose

Objectives and Definition of Project

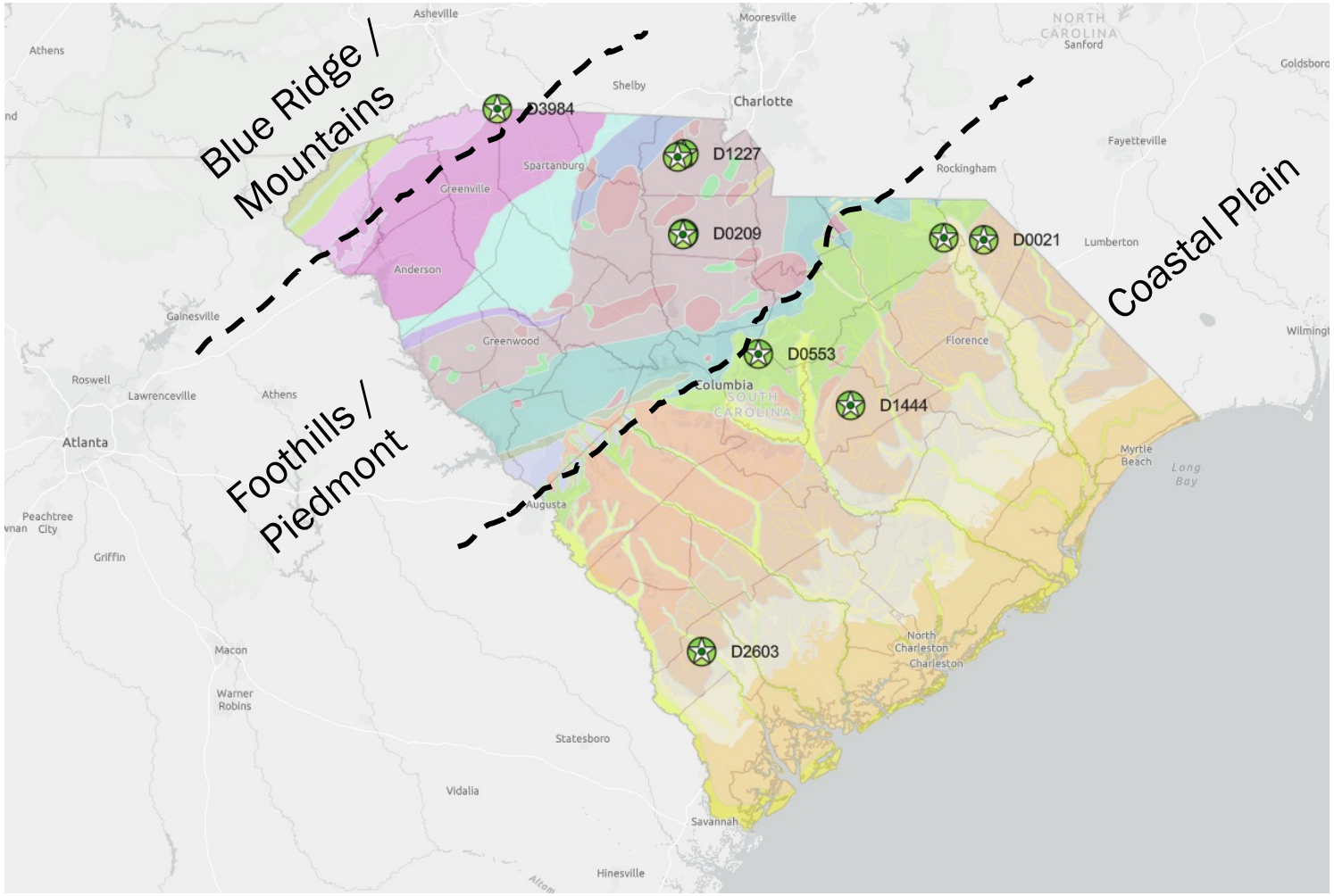
Purpose and Scope of HHPD Grant Funding for SC Dam Safety (1)

- Goals for FY19 Grant Period: Reduce Risk!
- Prioritize dams – based on eligibility and other factors
  - "Poor" or "Unsatisfactory" inspection rating – and not because of neglect
  - Public ownership
  - Potential for risk reduction
- Introduction to risk-based framework by SC Dam Safety that meet FEMA criteria
- Evaluation of static, hydrologic, piping/internal erosion, and seismic failure modes

Purpose and Scope of HHPD Grant Funding for SC Dam Safety (2)

- Criteria for selection and dam owner cooperation was established early
- Variety of dams
- Geographically diverse
- Varying conditions and background information available
- Initial selection was about 22 dams, cut list down to 10

HHPD Grant-Funded SQRA - Geology



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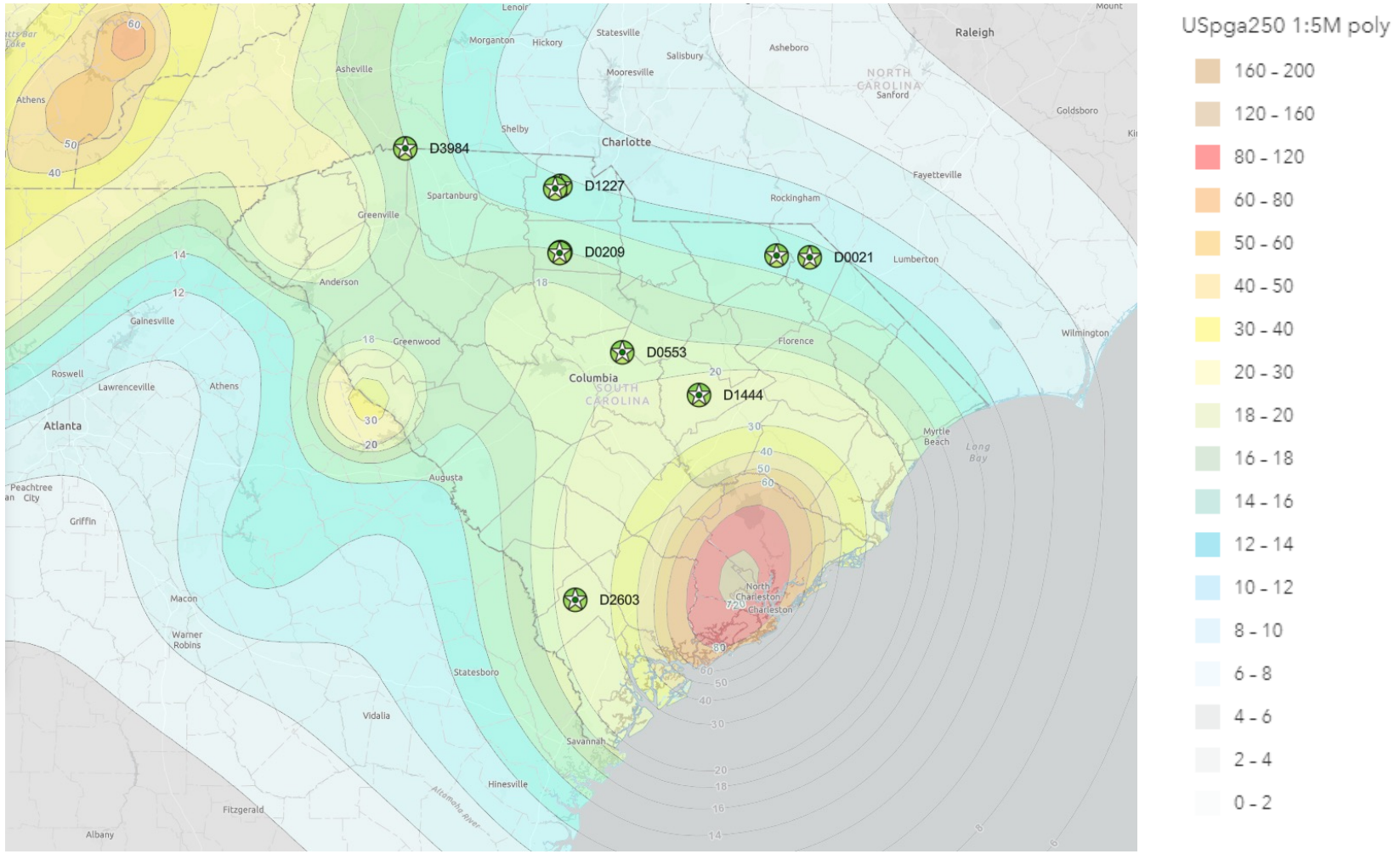
HHPD Grant-Funded SQRA - Seismicity



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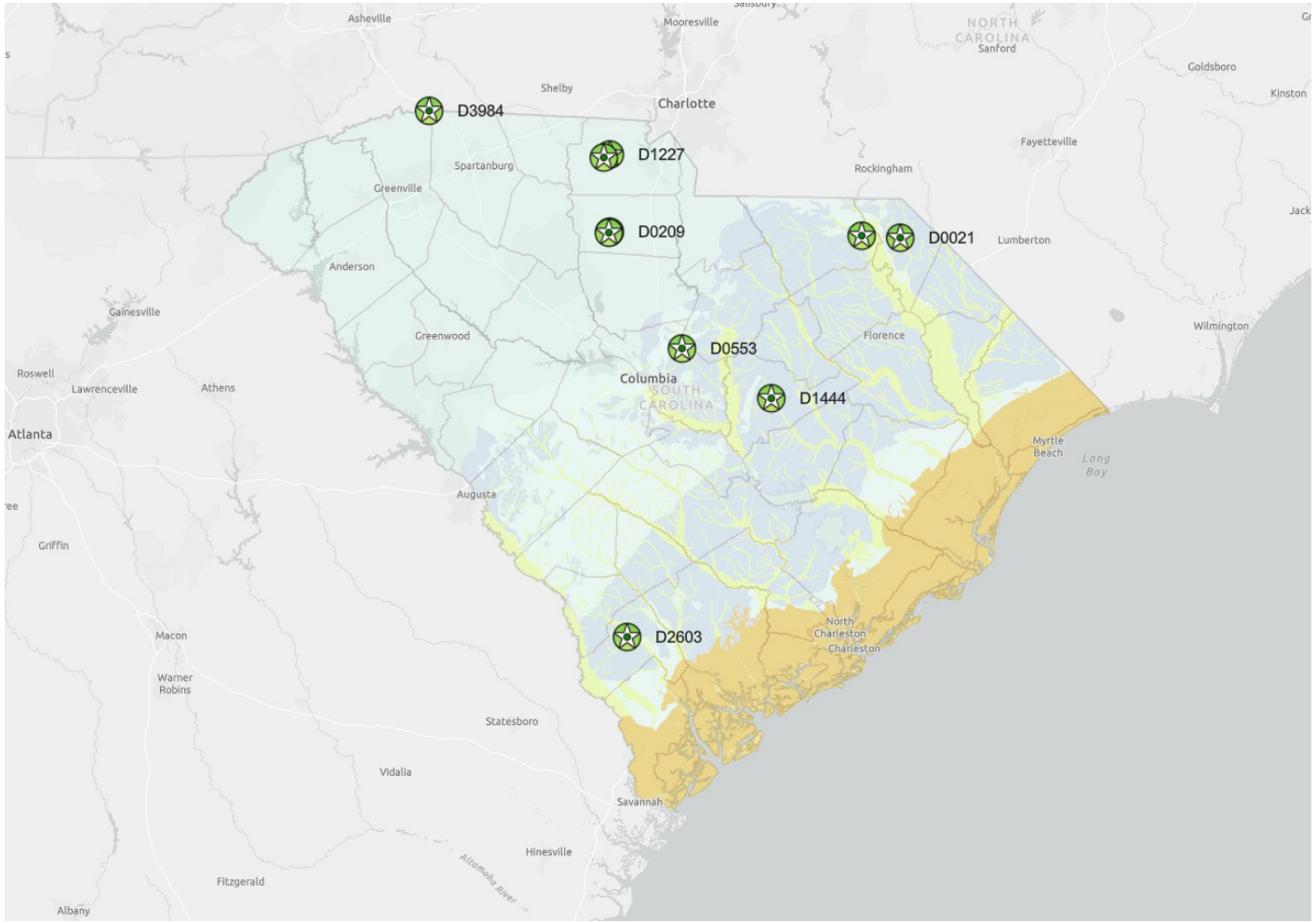
HHPD Grant-Funded SQRA – Seismic Hazards

Geologic Hazards

- Low Geologic Hazard Potential
- Low Potential for Liquefaction
- High Potential for Liquefaction
- Other Geologic Hazard (landslide, sinkhole, collapse)



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Prioritization of Dams for FEMA HHPD Semi-Quantitative Risk Analysis (SQRA)

SLRA, Eligibility and Initial Risk Assessment

Screening Level Risk Analysis (SLRA) on High Hazard Dams….
Okay, what's next?

How to screen highest risk dams?

- Known database of flagged dams
- Subjective inspections
- Political influences and ownership

Cost effective and fast

- Available data
- Remove subjectivity
- Consistent information across all dams

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Screening Level Risk Analysis (not specifically a part of HHPD) (1)

Total Risk Factor = (Hazard)^a x (System Performance)^b x (Consequences)^c

Hazard

- Seismic and Hydrologic (and Static)

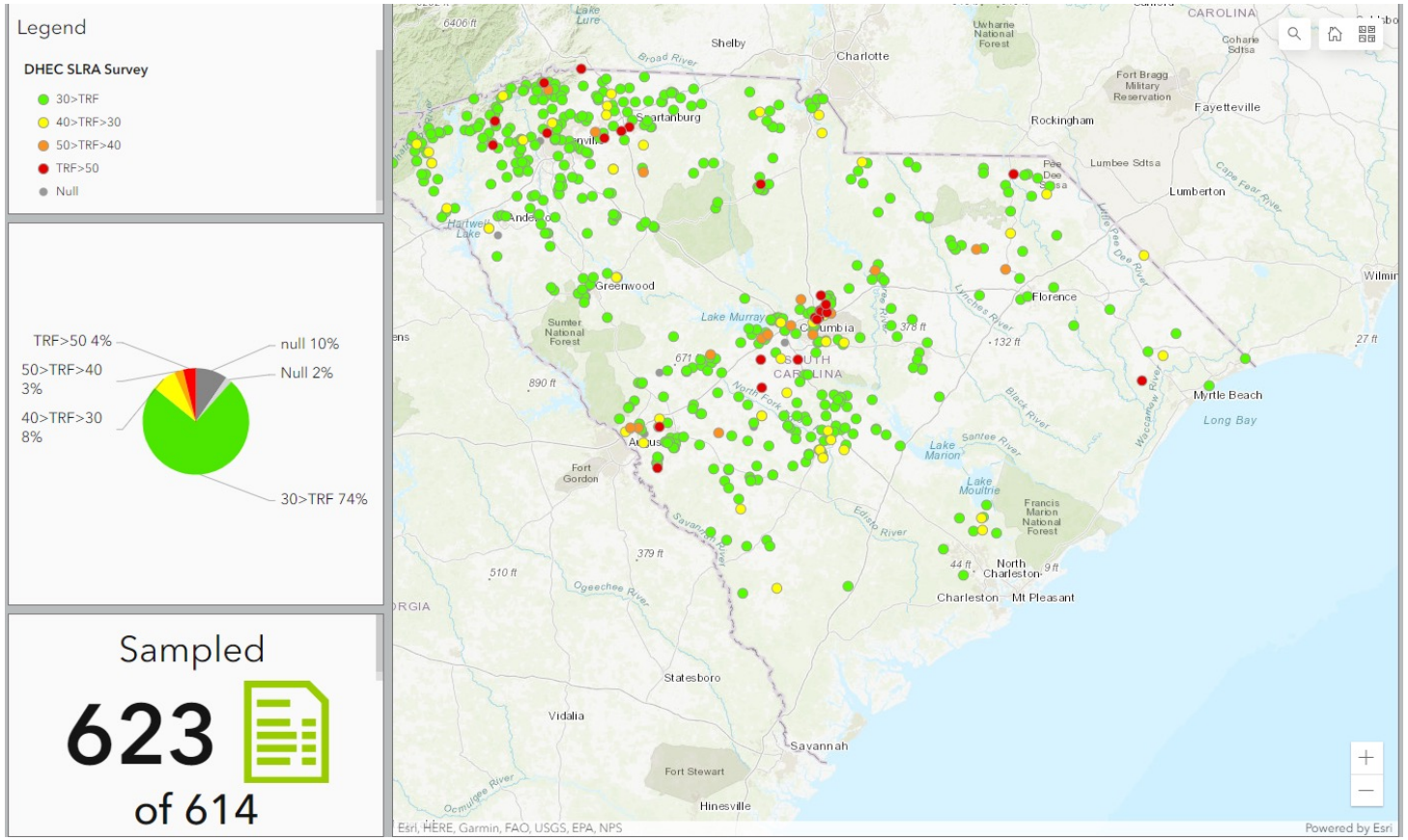
System Performance

- Inspection Reports

Consequences

- Population at Risk (PAR) from DSS-WISE

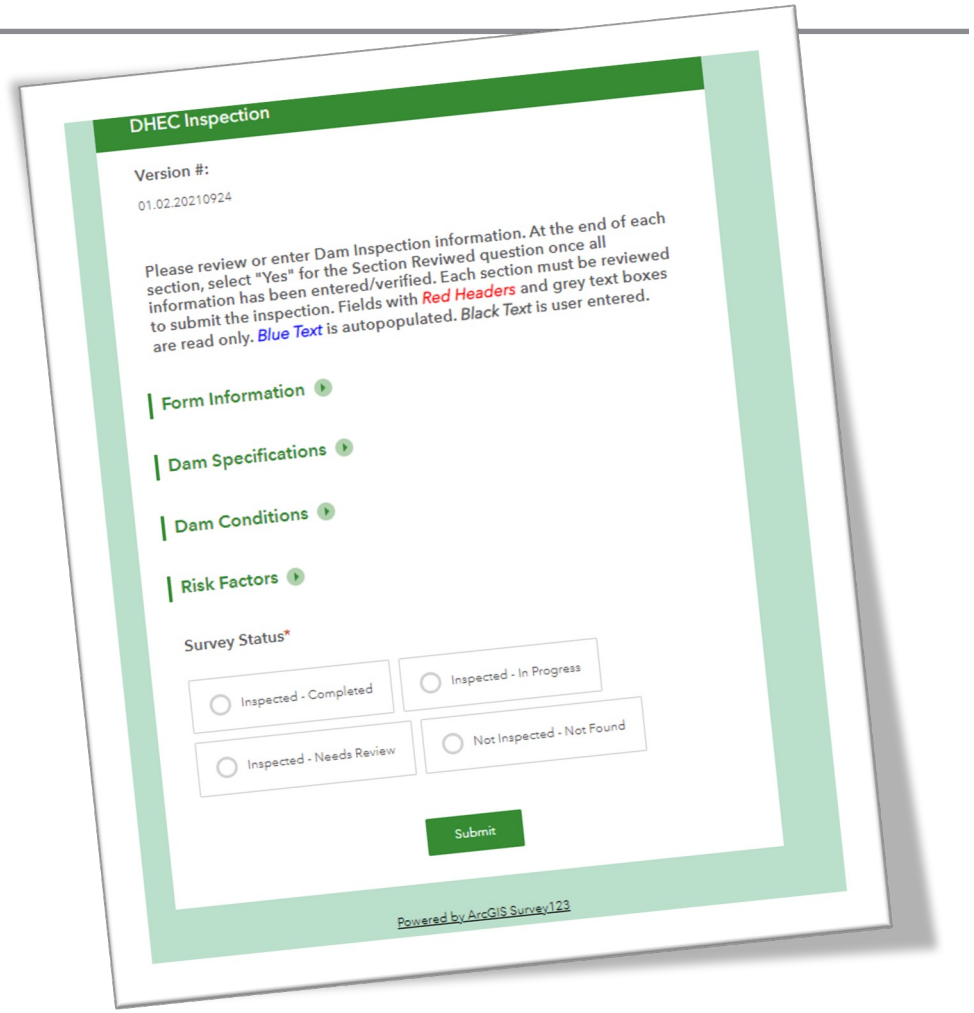
ArcGIS Dashboard



Screening Level Risk Analysis (not specifically a part of HHPD) (2)

1. Live updated based on inspections
2. Updated if risk reduction measures are taken
3. Updated after permitting work / construction / repairs
4. Framework improvements and updates
5. Prioritization

6. Informed selection for SQRA



Further Analyses and Information Gathering for SQRA

Further Analyses and Information Gathering (1)

1. Missing as-built and construction drawings
2. Missing geotechnical information
3. Missing hydrologic information
4. Accuracy or quality of information
5. Consistency of information
6. Knowledge of dam history

Figure 1-2 1926 – Emptying Event (Asheville Citizens Times Newspaper)

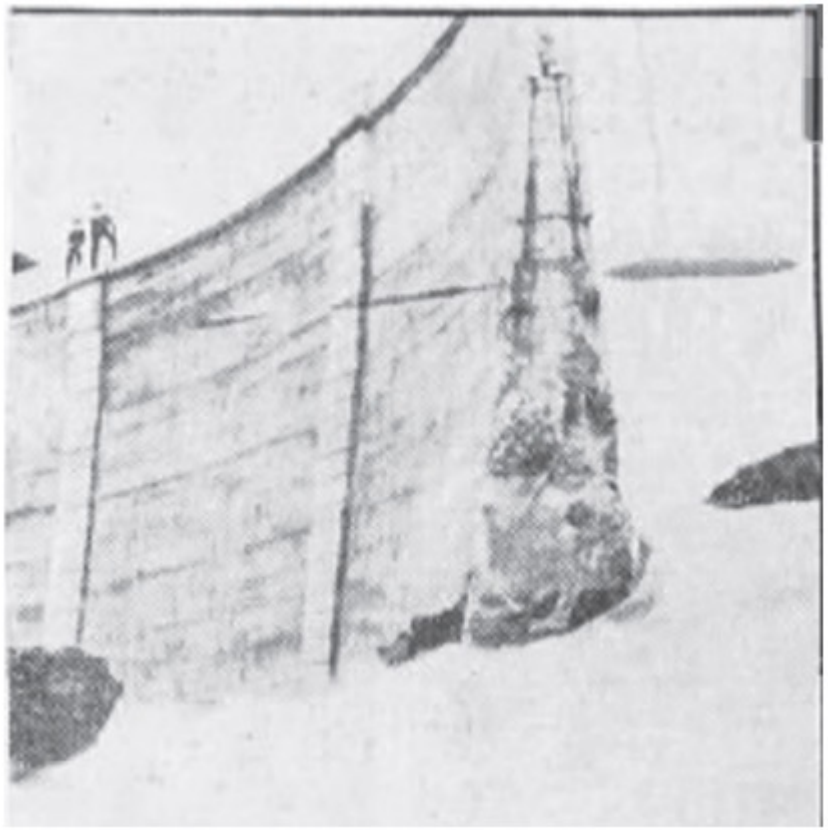
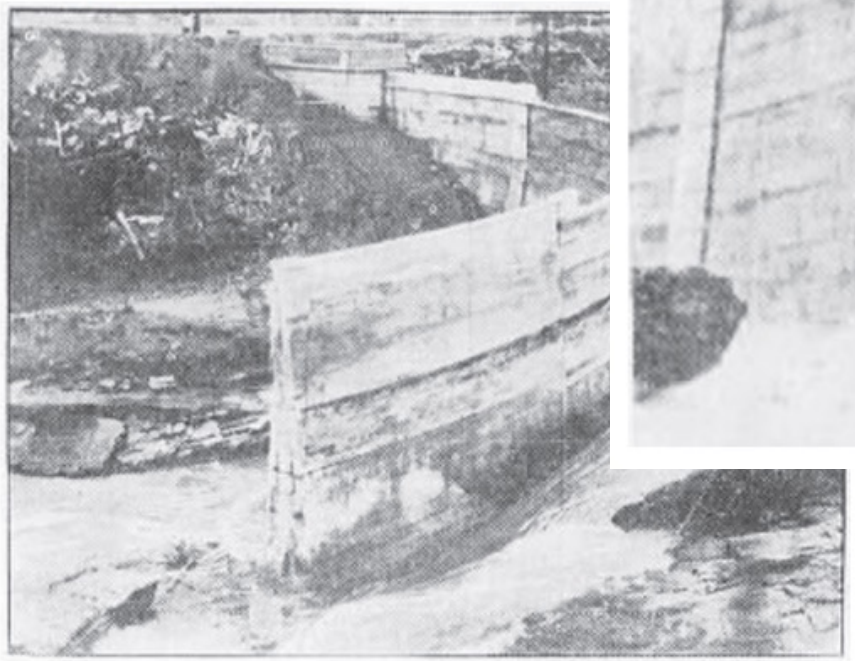


Figure 1-1 1926 – Concrete Arch (Asheville Citizens Ti



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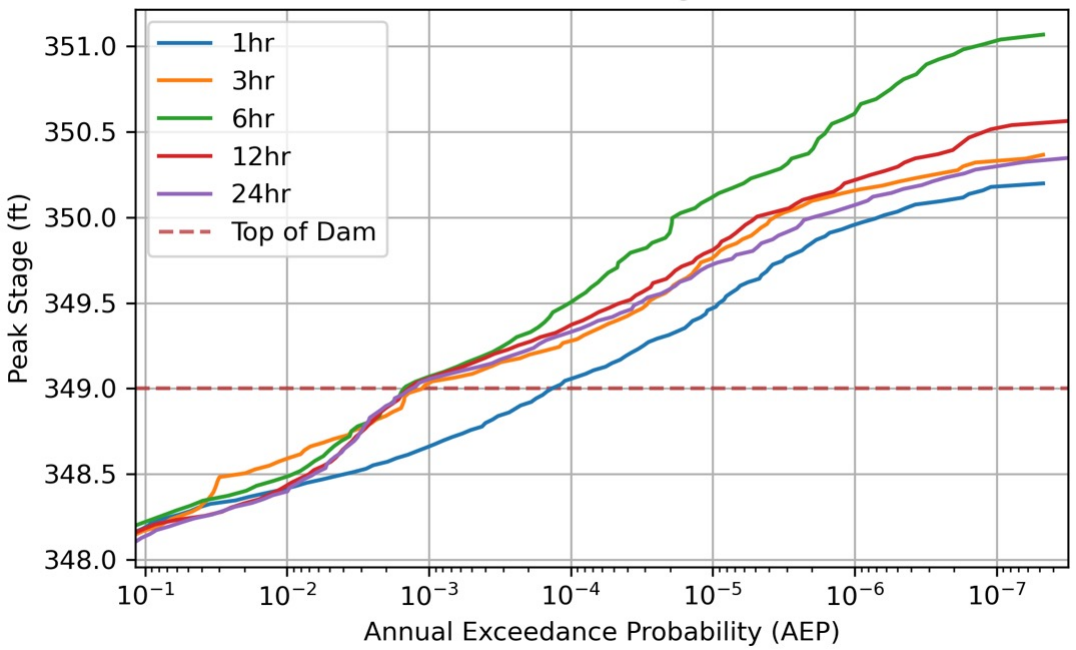
Further Analyses and Information Gathering (2)

1. Site simplified survey and visual inspection
2. Site visit with drill rig to conduct field testing and to collect soil samples for laboratory testing
    a. Erodibility of embankment
    b. Stability of embankment
    c. Seepage characteristics of embankment

Further Analyses and Information Gathering (3)

1. Gathered spillway and topographical information
   a. Spillway size, dam and watershed characteristics, elevations
   b. Upstream dam studies
2. Performed advanced Hydrologic and Hydraulic modeling (Research Triangle Institute) using Rainfall Runoff Frequency Tool (RRFT)
3. Developed hydrologic hazard curves: Stage frequency, Depth duration, duration above crest, inflow volume



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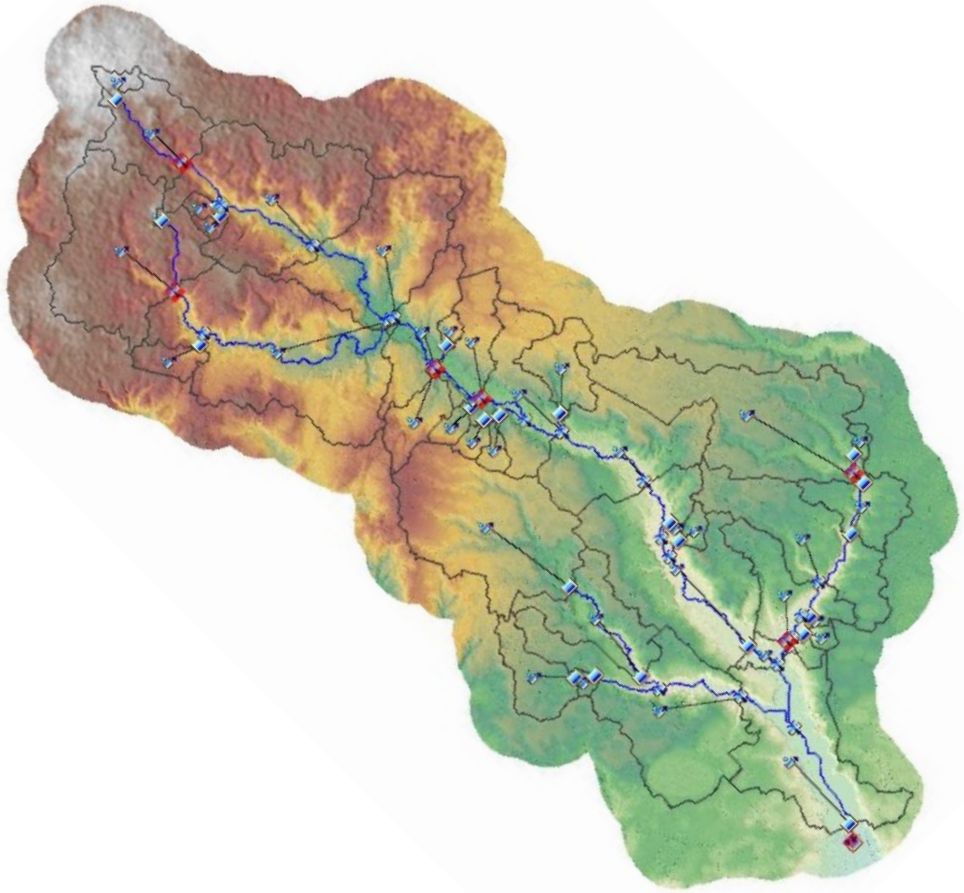
Further Analyses and Information Gathering (4)

1. CDM Smith and SC DHEC gathered information on upstream dams to be included in modeling
2. Used terrain data (typically 1- to 3-meter LiDAR data – Thank you DNR!)
3. Smaller upstream dams assumed to overtop and not fail
    a. Stage-storage-discharge curves for all upstream dams using GIS routines



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Further Analyses and Information Gathering (5)

1. Used 5 different storm patterns, 5 max events, 10 dams (250 unique hyetographs in total)
2. Used the stage frequency curves and scaled storm events for each dam to determine critical inflow hydrographs to develop breach characteristics (Q_p, t_f, b_w, etc.)
3. Used information in development of consequences and failure likelihood

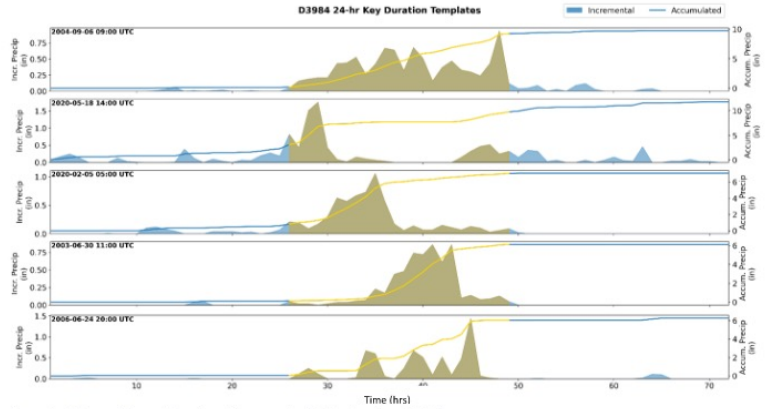
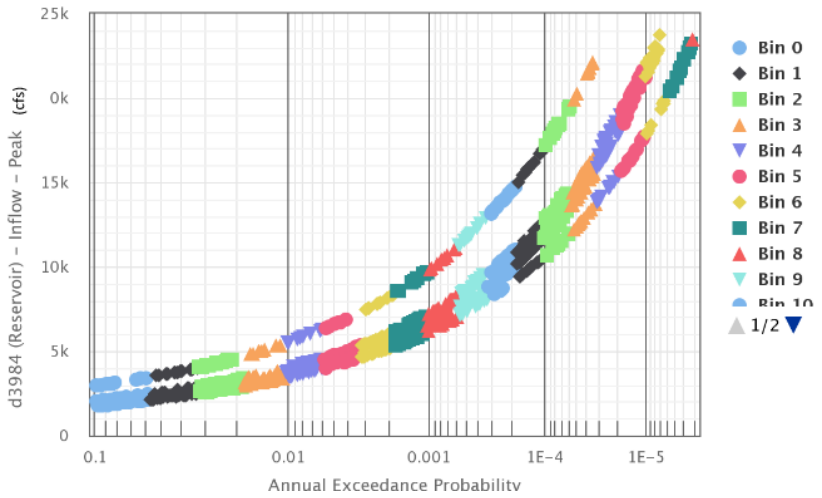
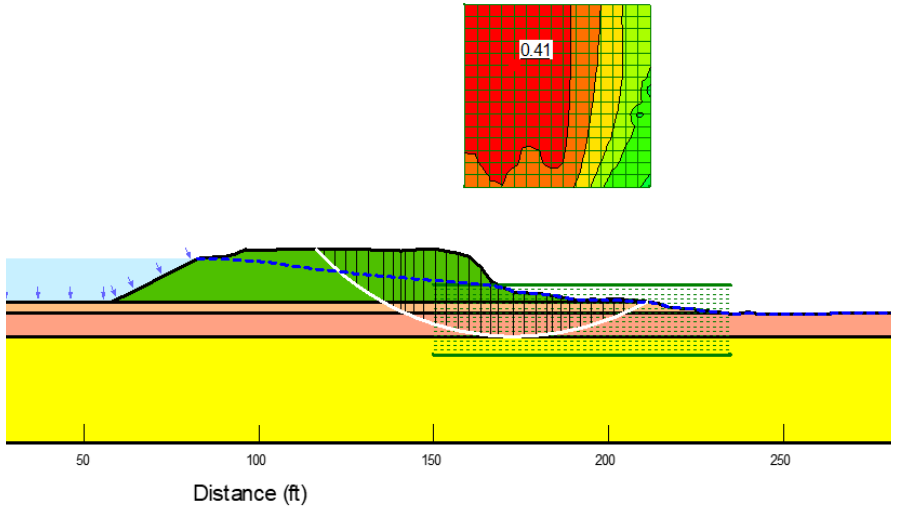


Figure 3-6: Example Storm Template Hyetographs (24-hr duration, D3984)



Further Analyses and Information Gathering (6)

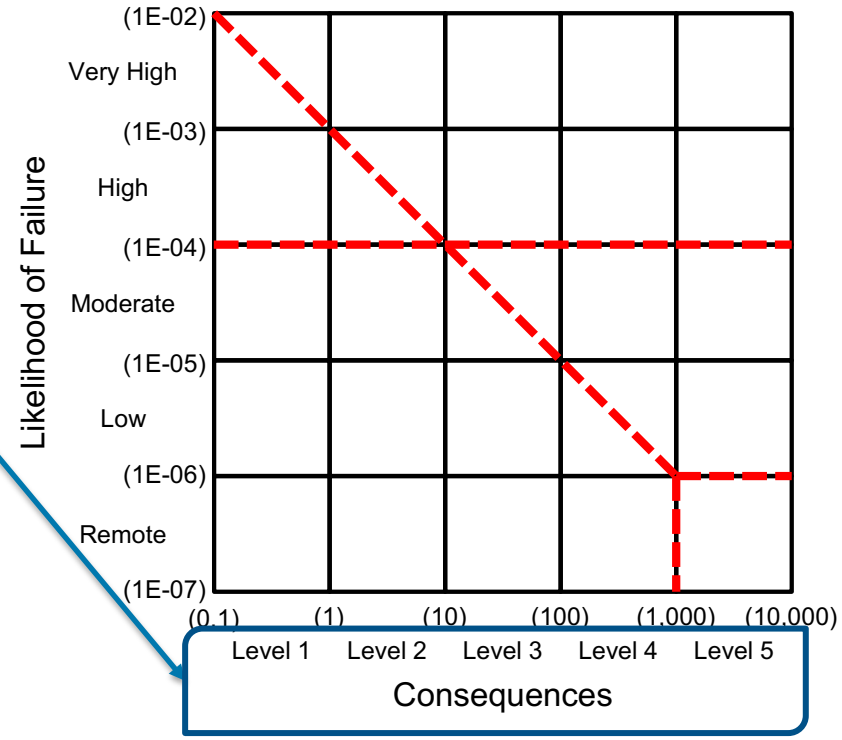
1. Geotechnical analyses
   a. Generalized seepage and stability analyses
   b. Seismic hazard analyses – Liquefaction and seismic deformations
   c. Pseudo-Static stability & Post Earthquake Stability



West Abutment Slough

Further Analyses and Information Gathering (7)

1. CONSEQUENCES
   a. Using DSS-WISE Lite Human Consequence Module (HCOM) to assess Population at Risk (PAR)
   b. Outflow hydrographs* with breach and non-breach scenarios to evaluate incremental PAR for overtopping
   c. Sunny Day Breach at normal pool to evaluate Internal Erosion, Static & Seismic PAR



DSS-WISE™ Web Login

Decision Support System for Water Infrastructural Security Web

*Breach & Non-breach hydrographs were generated using calibrated H&H information w/ WinDAM C

Semi-Quantitative Risk Assessments

Potential Failure Mode Analysis (PFMA) Workshops

SQRA Workshops (1)

- Facilitators – USACE and CDM Smith
- SC DHEC (Regulator) Permitting Engineers and Regional Engineers
- SME – Subject Matter Experts
- Dam Owners
- Dam Owner's Engineers
- Dam Maintenance and Operation Staff
- Other Agencies and Stakeholders: SCDOT, NCDEQ, SC DNR, Parks and Rec staff, Emergency Management Staff

SQRA Workshops (2)

- Specific Potential Failure Modes (PMFs):
  - #1 Overtopping
  - #2 Internal Erosion
  - #3 Static Slope Stability (Slope Stability)
  - #4 Seismic Stability (including Liquefaction assessment)
- Budgeted 4 hours for 3-4 SMEs
  - Typically took 4-8 hours total between 1 and 3 different sessions
  - Follow-up items and meetings

SQRA Workshops (3)

- PFM#1. Overtopping
  - SME poll on elevation that would certainly fail the dam
  - Determine most likely location of overtopping
  - Annual Exceedance Probability = System Performance
  - Typically dominates risk, however, not always
  - Majority of time spent on discussing this failure mode!

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SQRA Workshops (4)

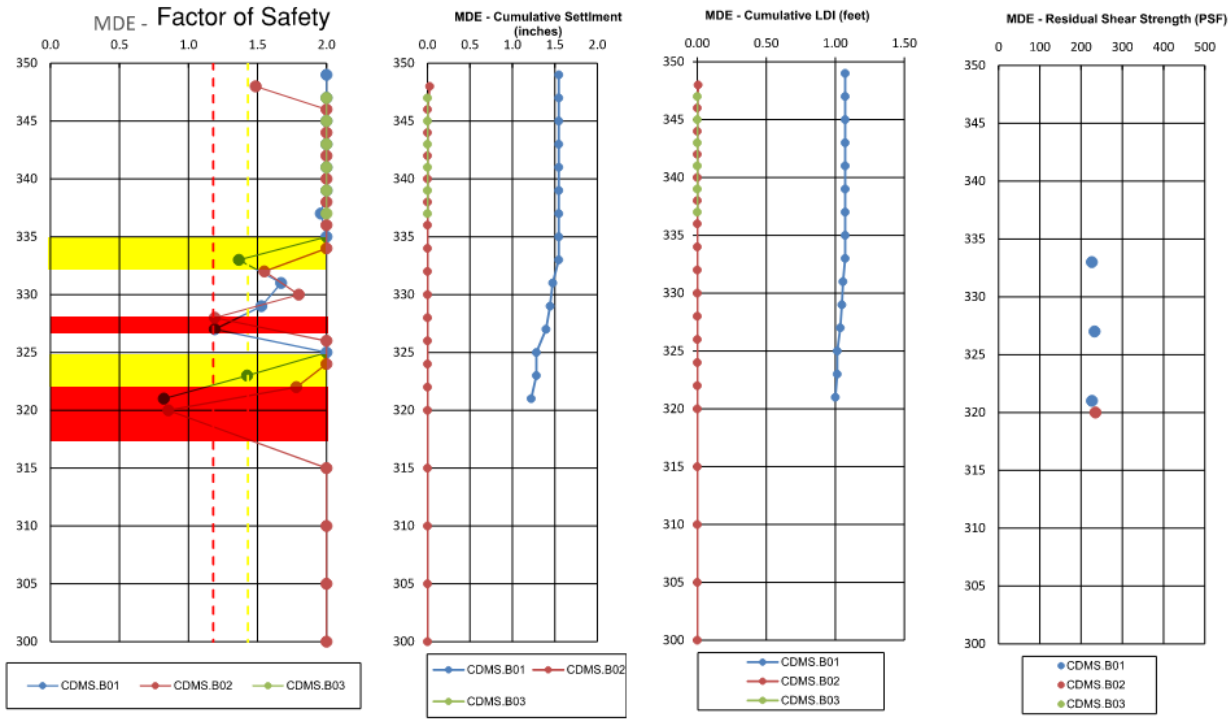
- PFM#2. Internal Erosion (Most difficult to assess!)
  - Past or existing evidence of seepage problems
  - Assess general erodibility of embankments
  - Determine most likely location of internal erosion
  - Two Mechanisms
    - Concentrated Leak Erosion
    - Backward Erosion Piping
  - USACE erodibility tools / worksheets

SQRA Workshops (5)

- PFM#3. Static Stability
  - Geotechnical exploration quality
  - Quality of analyses depends on quality of input
  - Laboratory test results for strength of soils
  - Construction techniques
  - Likelihood of failure that leads to dam failure

SQRA Workshops (6)

- PFM#4. Seismic Stability and Liquefaction assessment
  - Idriss and Boulanger 2008 procedures
    - SPT and CPT correlations, where applicable
    - Occasionally just a screening
  - USGS Seismic Hazard Curves
  - Estimated displacement of slope
  - Assessment of freeboard
  - Evaluating the 144- to 2,475-year return interval



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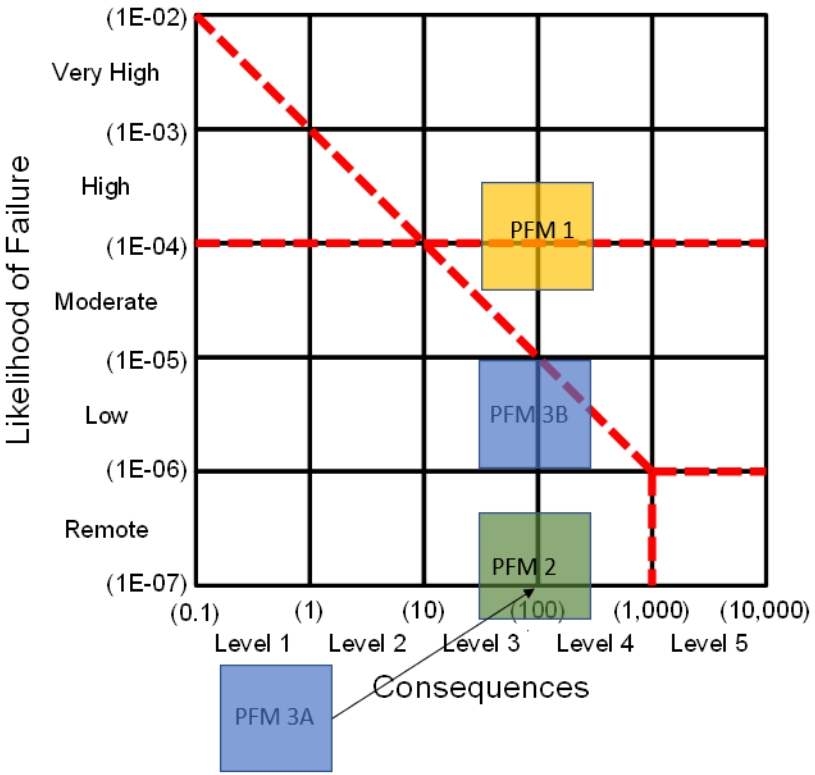
SQRA Results and Recommendations

Lake Lanier Dam

Figure 1-4 – Slough 1 (4/20/2020 S&ME Site Visit)

Figure 1-5 – Upper Scarp at Slough 1 (7/22/20 S&ME Site Visit)



- PFM 3A –Static Slope
- PFM 3B- Seismic Slope

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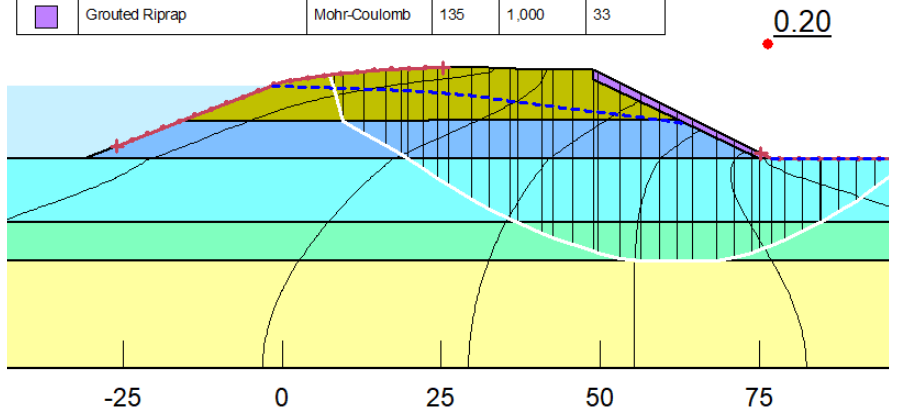
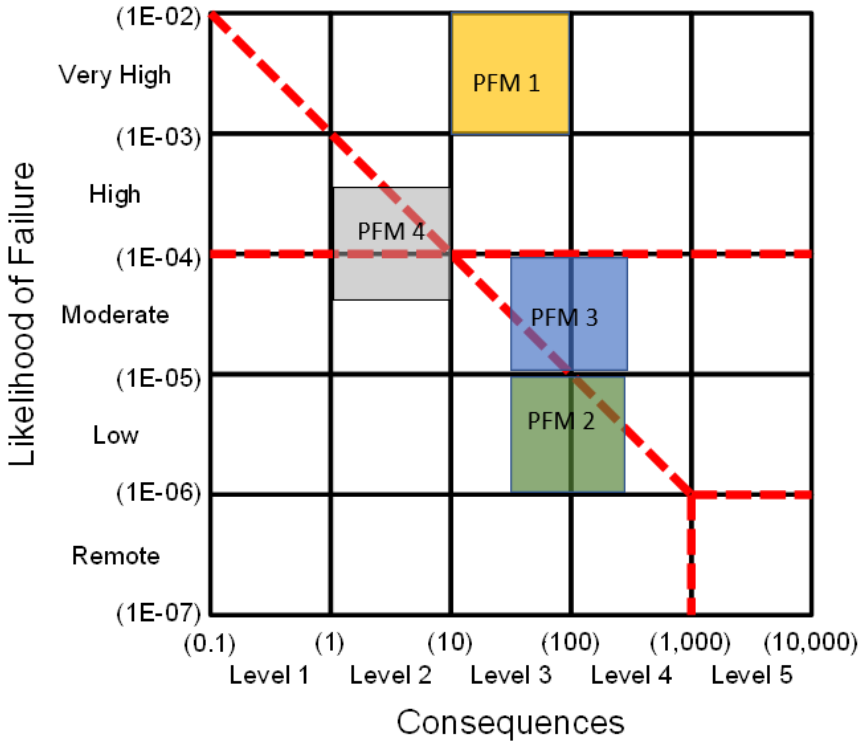
Second Millpond Dam

Figure 2 - Erosion of Eastern Dam Section

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)
	1. SM/SC (Fill)	Mohr-Coulomb	115	0	31
	1. SM/SC (Fill) (SSL)	Mohr-Coulomb	115	55	0
	2. SC/SM (Alluvium) (SSL)	Mohr-Coulomb	120	100	0
	3. SM/SP-SM (Alluvium)	Mohr-Coulomb	120	0	32
	3. SM/SP-SM (Alluvium) (SSL)	Mohr-Coulomb	120	100	0
	Grouted Riprap	Mohr-Coulomb	135	1,000	33





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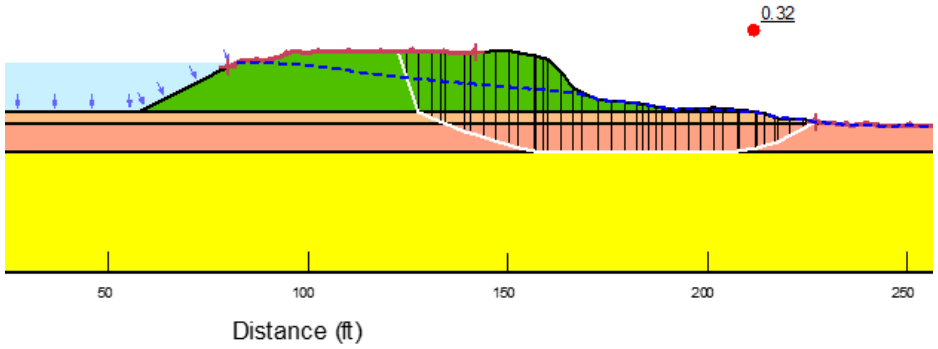
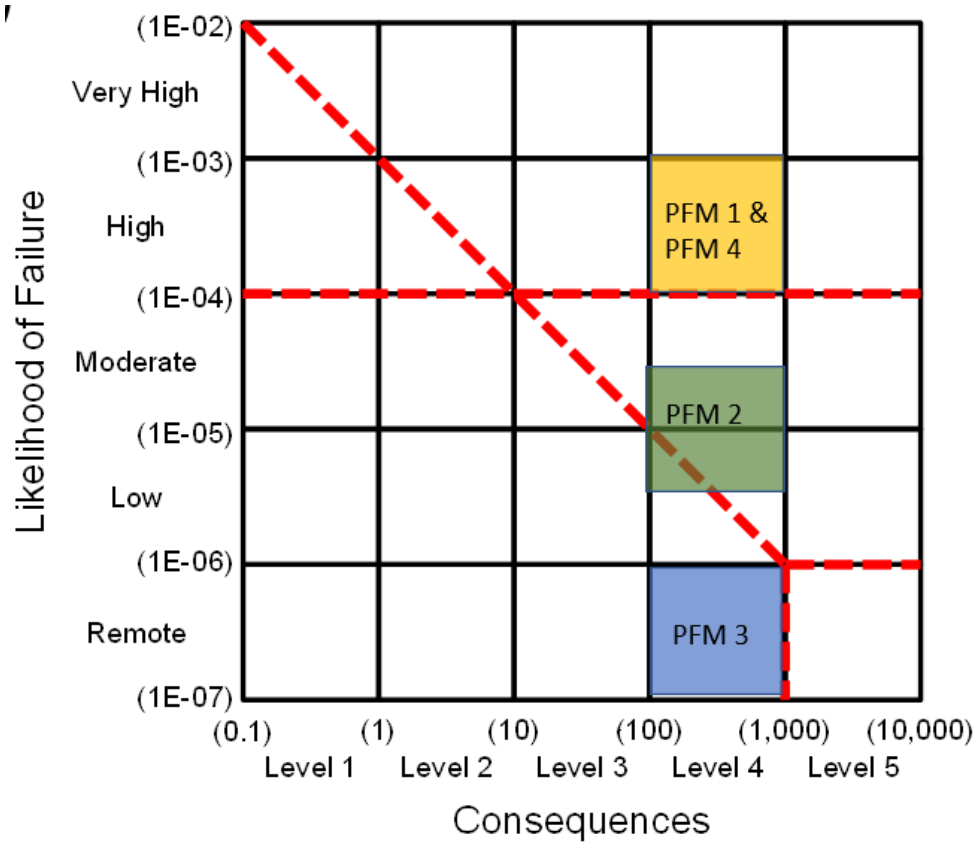
Lake Wallace Dam





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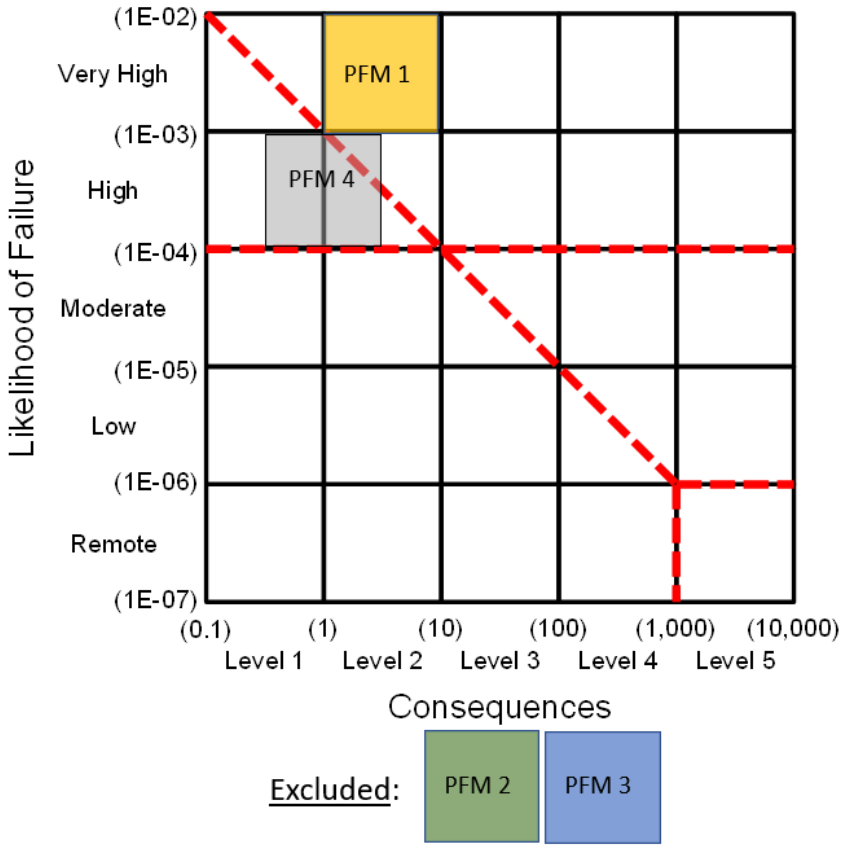
Lake Warren State Park Dam



Eureka Lake Dam

Figure 7 – 2018 Damage Photos showing scour along access road

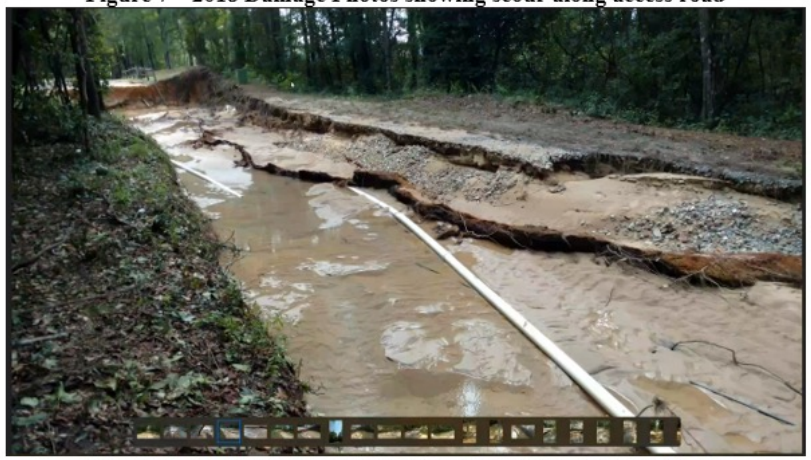
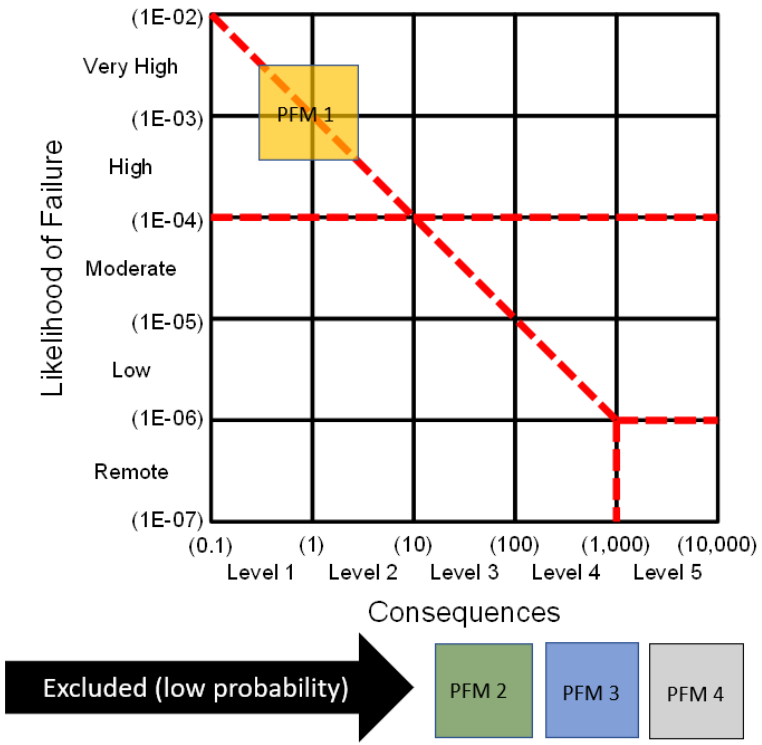


Figure 8 - 2018 Damage Photos showing scour along access road



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Sandhill Experiment Station Dam

Earthfill Dam (Continued)

C. Downstream Slope

(1) Seepage: check the embankment slope, toe, abutment contacts; denote the amount and location on schematic diagram.

A significant amount (10 gal/min estimated) of apparent seepage was observed approximately 20 feet below the toe of the dam. (See photo #3 and #4 and the attached schematic diagram)

Figure 1 - Clipping from 1981 SC LRCC Inspection Report

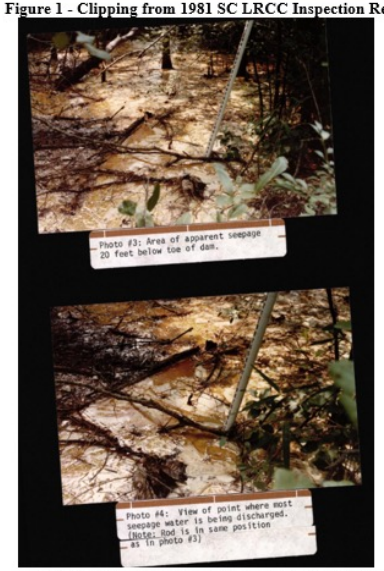
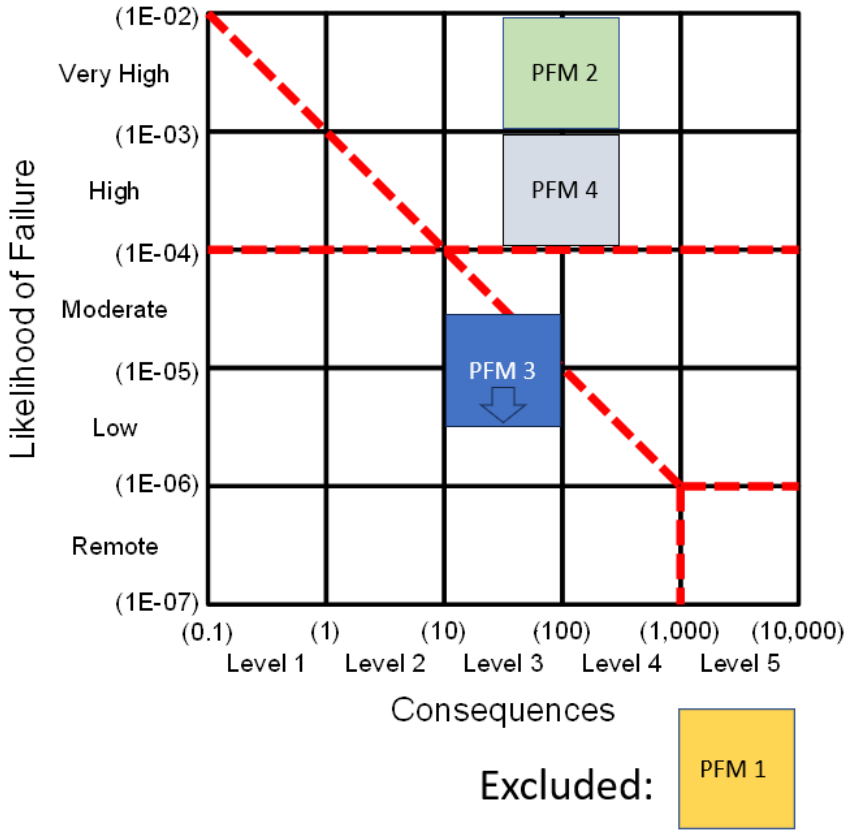


Figure 2 - Photographs from 1981 LRCC Inspection

6+00	5.3	102.8		X-Section
7+00	4.6	103.5	7+10	- Boil 20ft below Toe @ flowing water. Apparent Seepage.
8+00	4.5	103.6		

Figure 3 – Clipping from 1981 SC LRCC Inspection Notes



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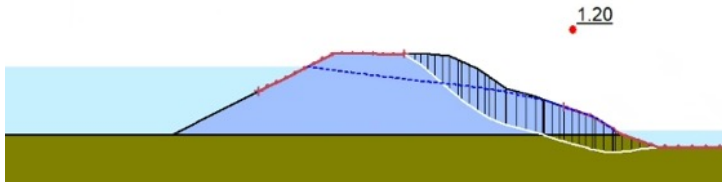
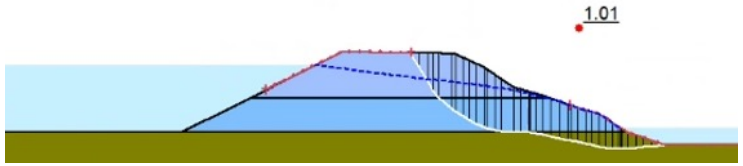
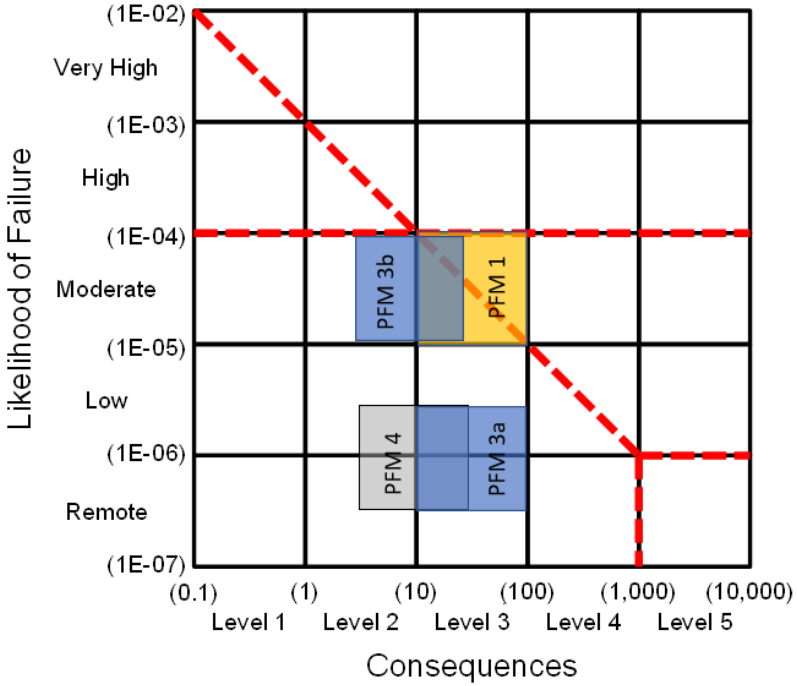
Upper York Dam

Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)
	1. SC-SM/CL (Fill)	115	50	29
	2. SM (Residuum)	120	50	33



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)
	1. SC-SM/CL (Fill)	115	50	29
	2. SM (Residuum)	120	50	33
	Soft Clay	105	250	0





EXCLUDED: PFM 2

- 3a – without soft layer and WSE at crest
- 3b – with soft layer and WSE at normal pool

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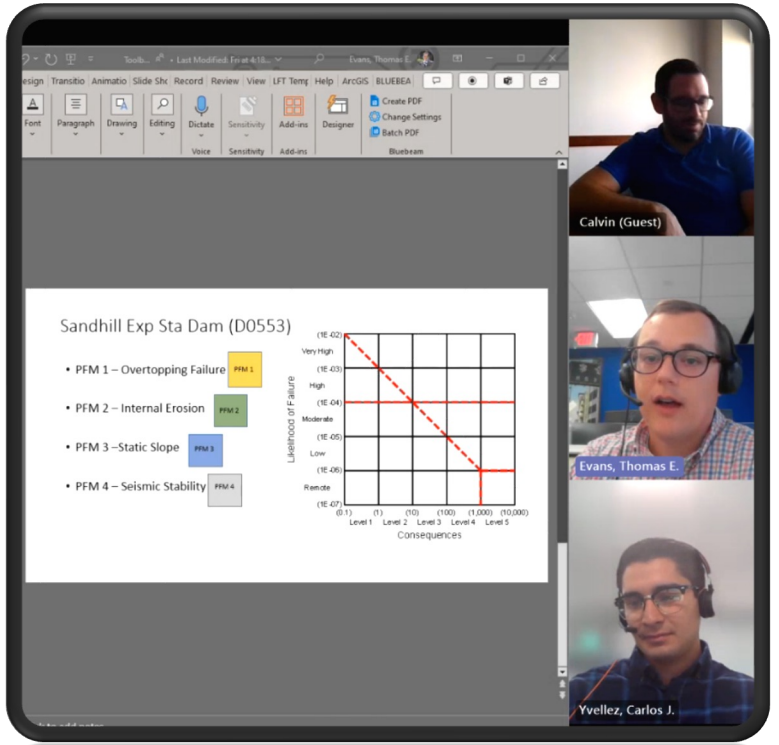
Lessons Learned and Key Takeaways

From SC DHEC SQRA

Lessons Learned and Key Takeaways (1)

1. Gather as much information ahead of time
2. Site visits with lots of photos
3. As-built information is key
4. Experienced facilitators are helpful
5. Diverse SMEs are important
6. Give team more time than you think you need – there's always more you can discuss!
7. Dam owners and operators are critical. There is no substitute for historical knowledge and dam performance.



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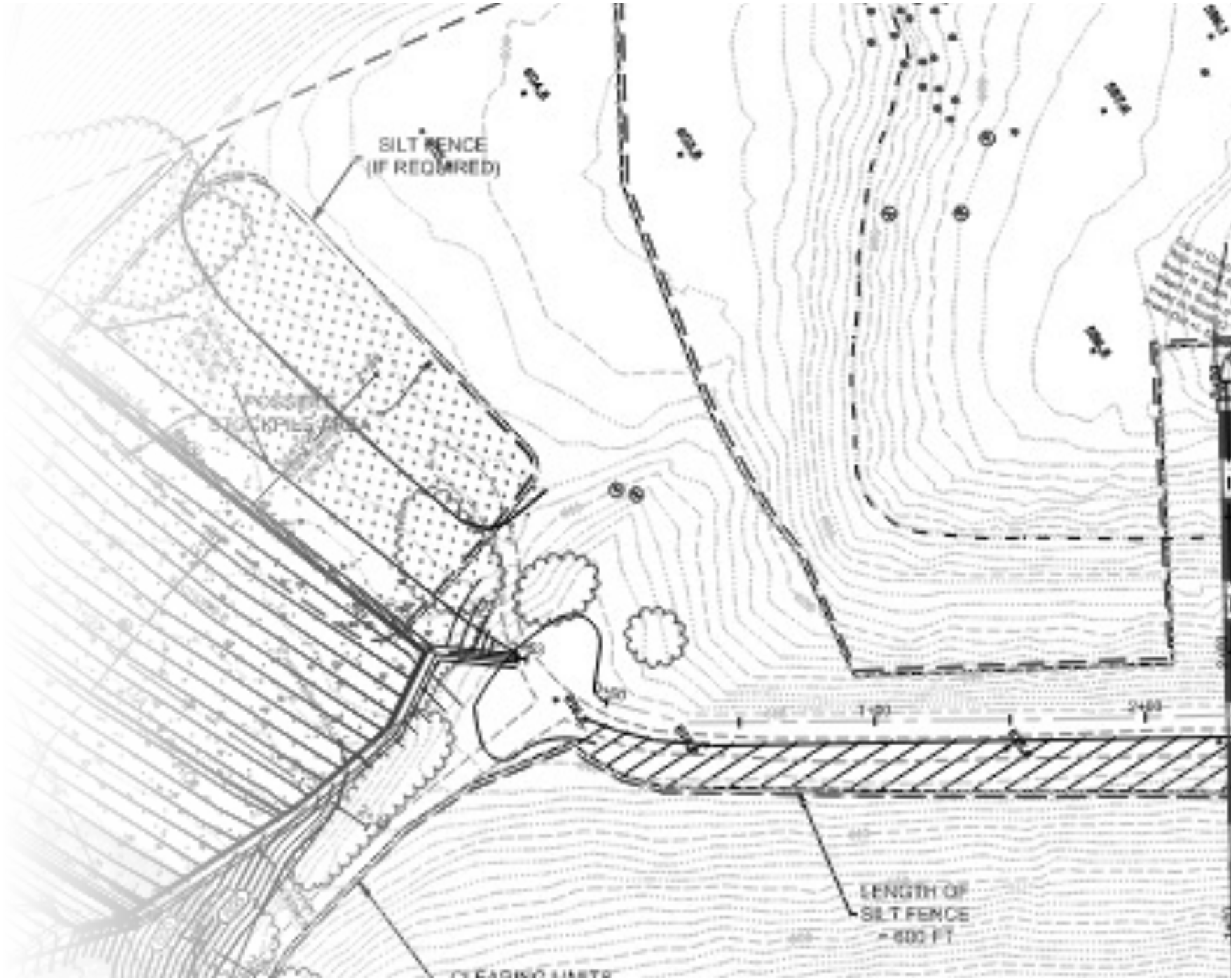
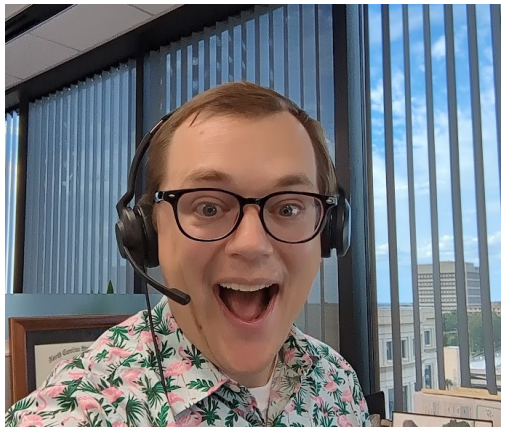
Questions?



Contact Us!

Thomas E. Evans, PE
Geotechnical Engineer
803-758-4524
EvansTE@cdmsmith.com



Stephen L. Whiteside, PE
Senior Vice President,
Dams and Levees Discipline Leader
WhitesideSL@cdmsmith.com

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