

Dam Safety 101 for the Future

National Dam Safety Program Technical Seminar | 2024

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- **As a US Army Corps of Engineers Infrastructure Leader (1980-2019):**
 - Owner and Self Regulator of +3,000 Infrastructure Systems
 - Changed culture from Standards to Risk Informed Decision-Making
 - Career Geotechnical Professional
- **As Private Consultant (2018-today)**
 - Sort of The Same Thing for Clients in Industry and Government



Pulpit Rock, Norway

(2,000 feet above the fiords of Norway)

My Risky Background in Dam Safety

Discussion Topics

01

CONTEXT FOR DAM
SAFETY IN THE
UNITED STATES

02

WHAT CONSTITUTES
A STATE-OF-THE ART
DAM SAFETY
PROGRAM?

03

LESSONS OF WHAT
NOT TO DO

04

LESSONS ON WHAT
WORKS WELL



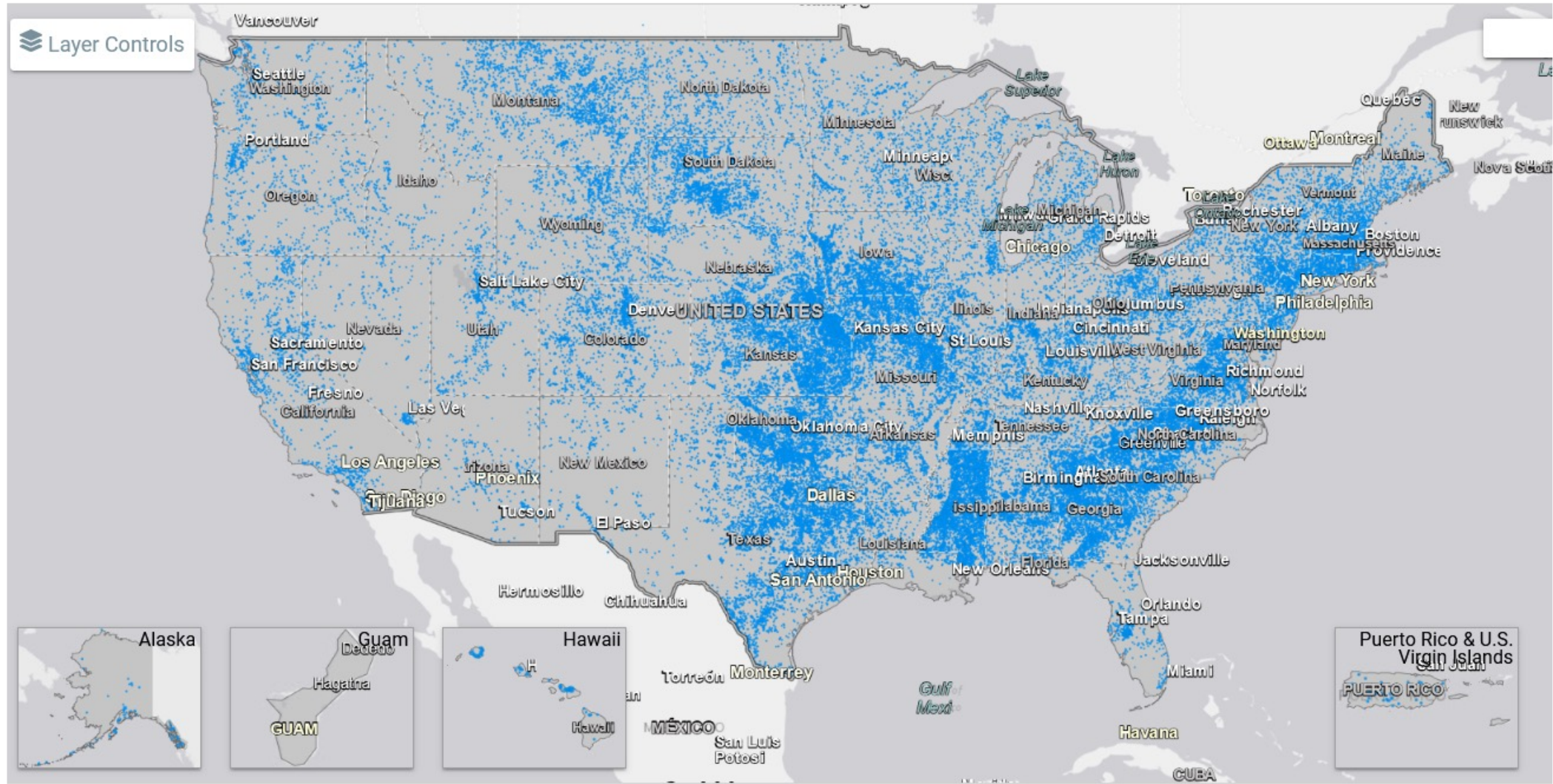
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CONTEXT FOR DAM SAFETY IN THE UNITED STATES

LESSONS FROM
MODERN DAM
SAFETY PROGRAMS

Let's look at some data

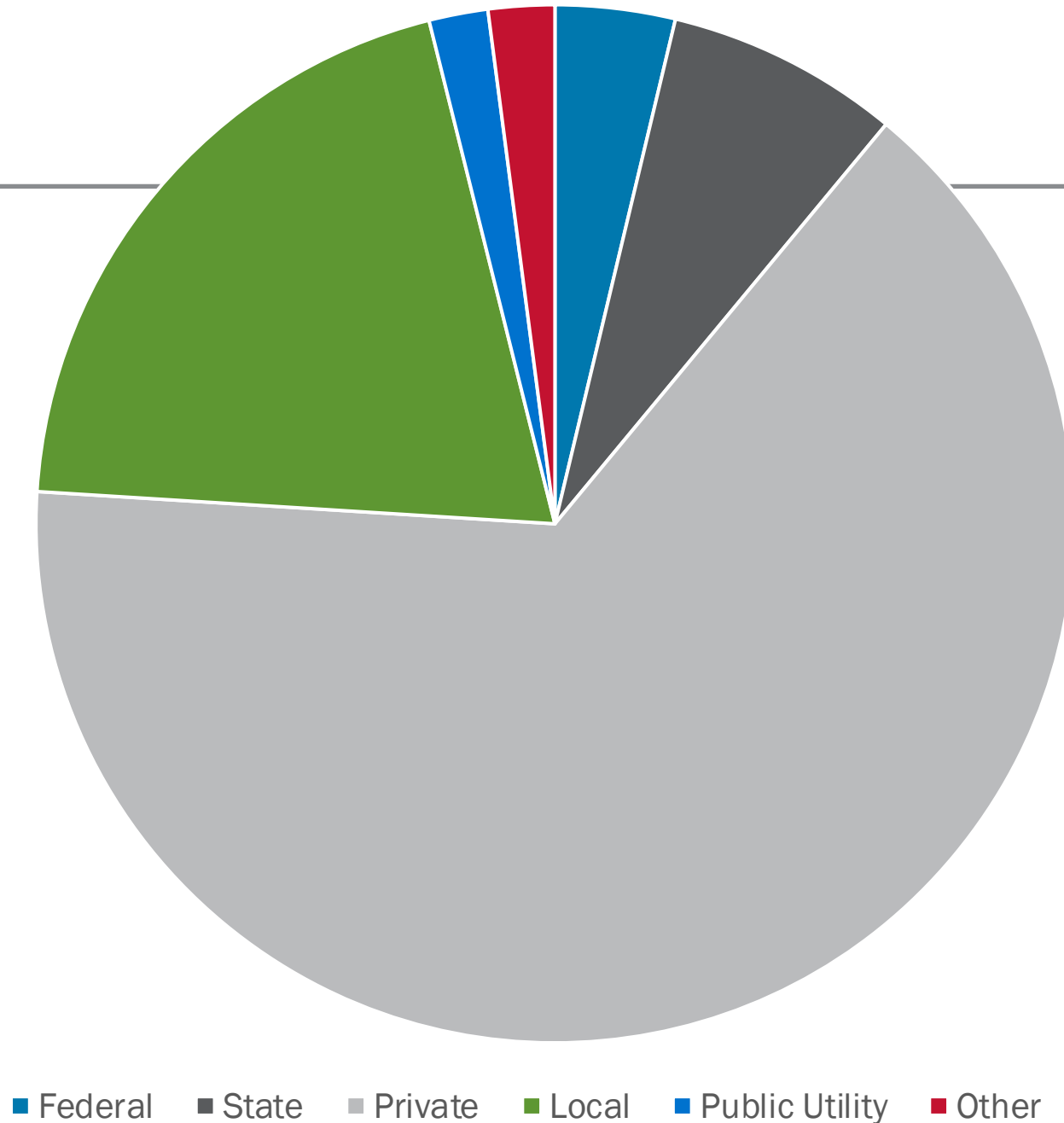
+91,000 dams Average Age = 61 years 6% federally regulated 70% state regulated



1. Flood control 2. Navigation 3. Hydropower 4. Water Supply 5. Environmental

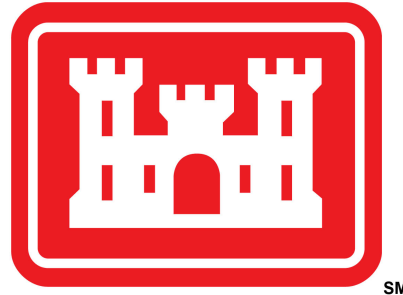
Dam Owners

- Common Law Legal System, Owners are Ultimately Responsible for Safety:
- Federal Owners Lead the Industry
- Some Owners are also Self Regulated
- Wide Range of Sophistication
- Decision Makers





US Bureau of Reclamation
Dam Safety



US Army Corps of Engineers
Risk Management Center



Tennessee Valley Authority
Dam Safety



Federal Energy Regulatory
Commission, Dam Safety

Federal Leaders

- Very Similar Policies and Approaches to Risk Assessment & Management
- Comprise Most of the Large, Complex and Risky Dams in United States
- TVA, USACE, and USBR are self-regulated Owners, FERC only is regulator
- Collectively, they have more experts in risk analysis and management than the entire US Industry
- All are senior, registered professionals that have 25-40 years experience.
- They are the leaders in Dam Safety and Risk Informed Decision Making

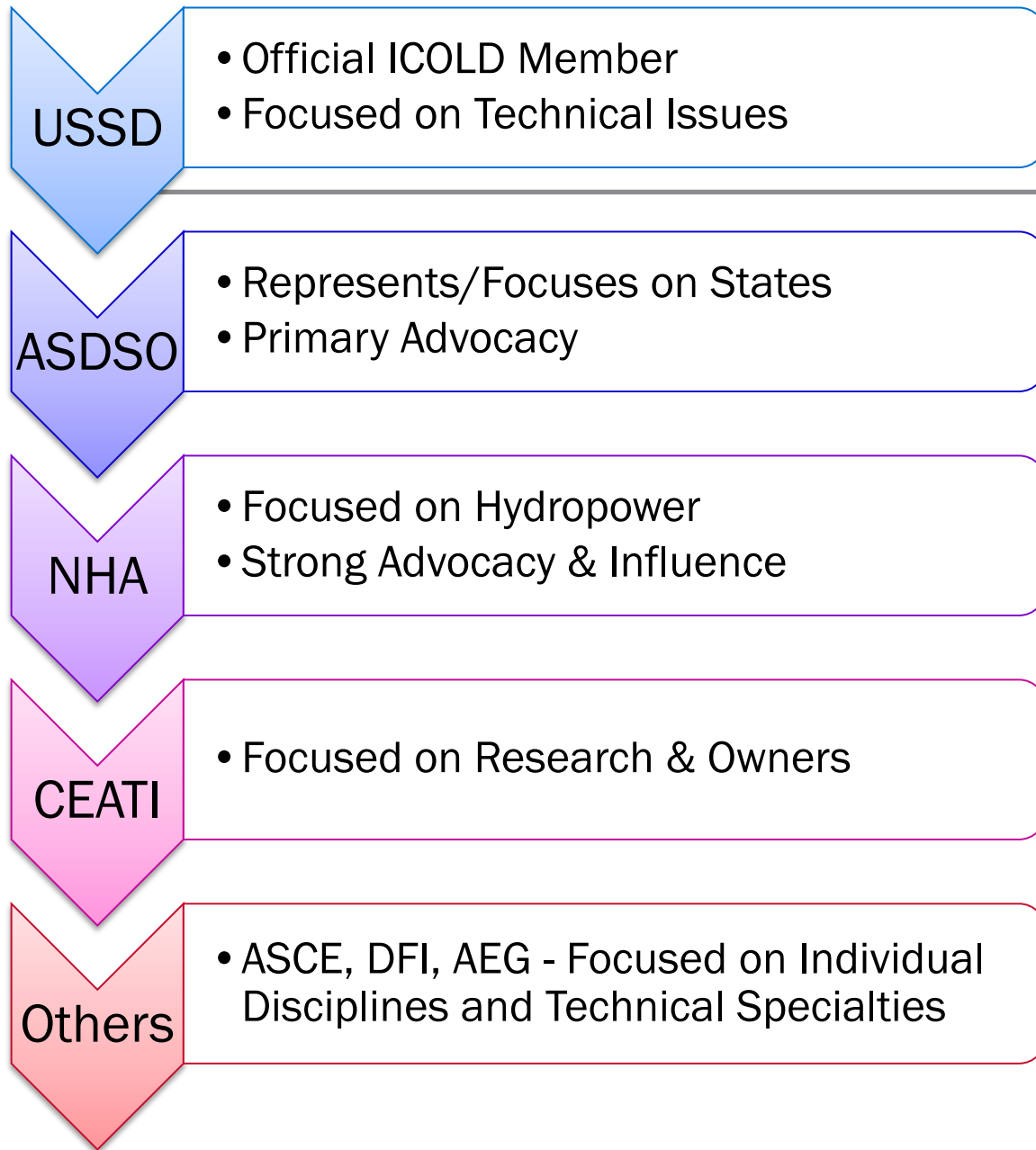
Dam Regulators

- States Primary Regulator but Vary Considerably – Some Embracing Risk
- FERC and Large Federal Owners Have Identical Regulatory Framework Based on Risk
- Some Dams are not Regulated

■ FERC

■ States

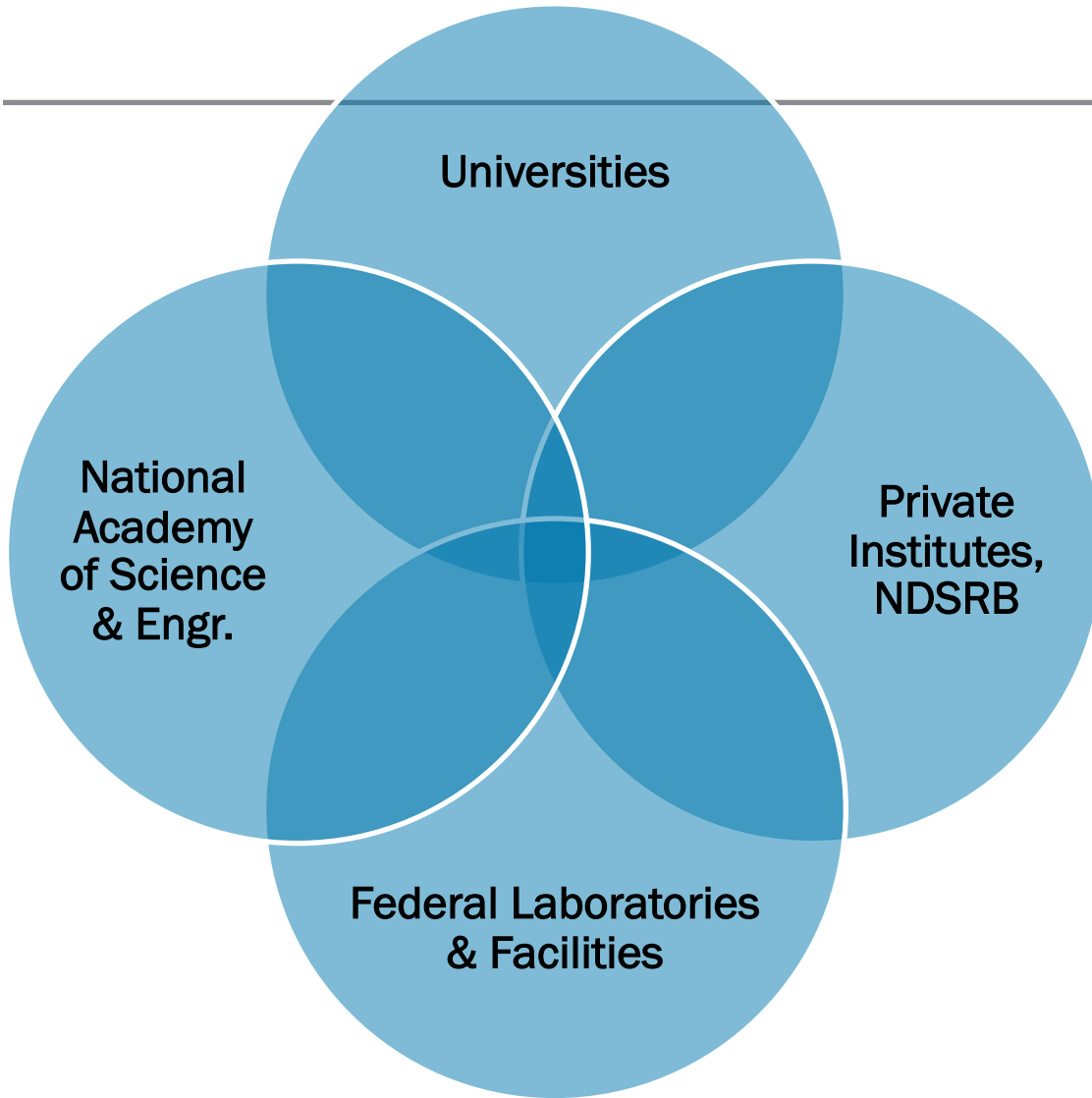
■ Federal Owner



Non-Governmental Organizations

- Help Guide the State of the Practice
- Much Overlap Between NGOs But Not Coordination
- Most Provide Training and Collaboration
- Common Membership of Federal, Academia, and Industry Experts

Academia and Dam Safety



Some Collaboration, Not Much – Mostly Competitive
With Each Other

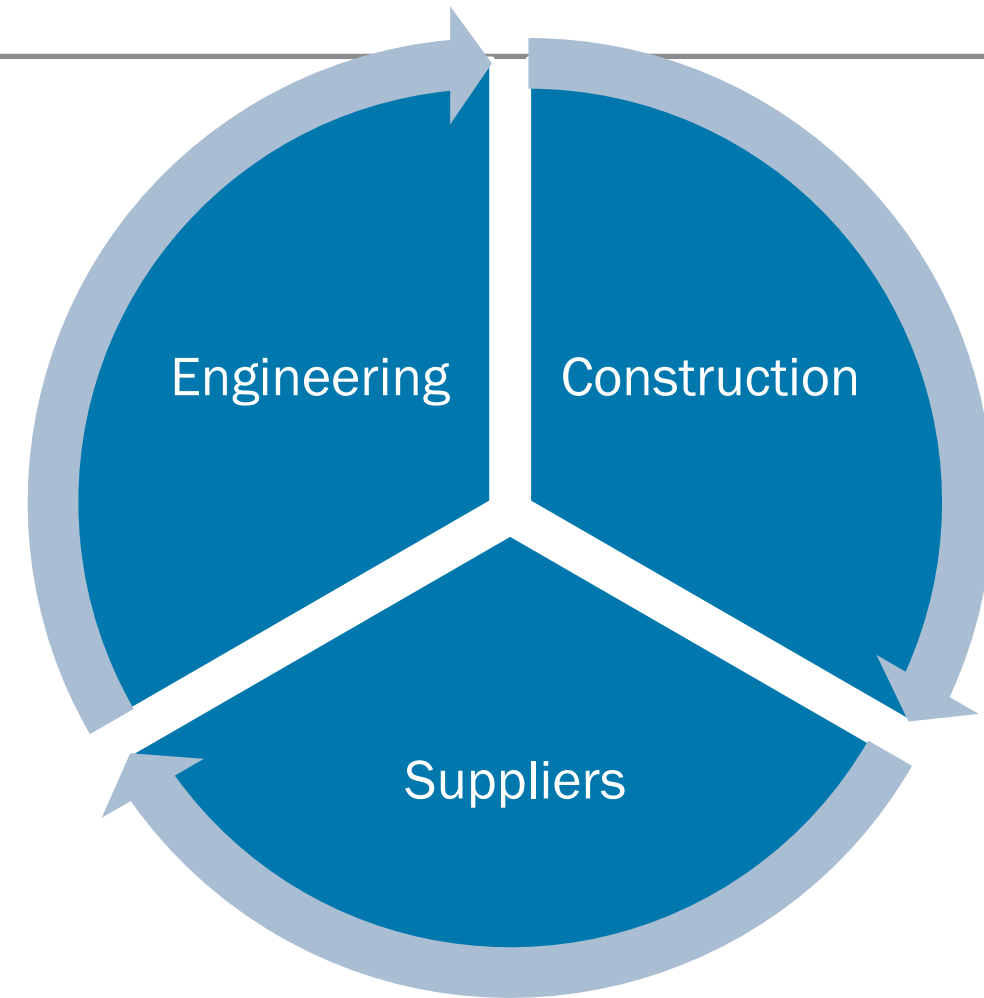
Little Central Funding from Government

Minor Focus on Dam Curricula and Risk in Universities

Federal Agencies of USBR and USACE Fund Most...

Decreased Funding of Science Agencies in United States

Industry & Dam Safety



- Very Few New Dams Being Built in USA, Most Construction is Rehabilitations.
- Most Engineering support focused on Assessments/Regulatory Compliance
- Not much collaboration between Industry Partners: Competition
- Risk Expertise in Government >> Industry
- Decision Influencers

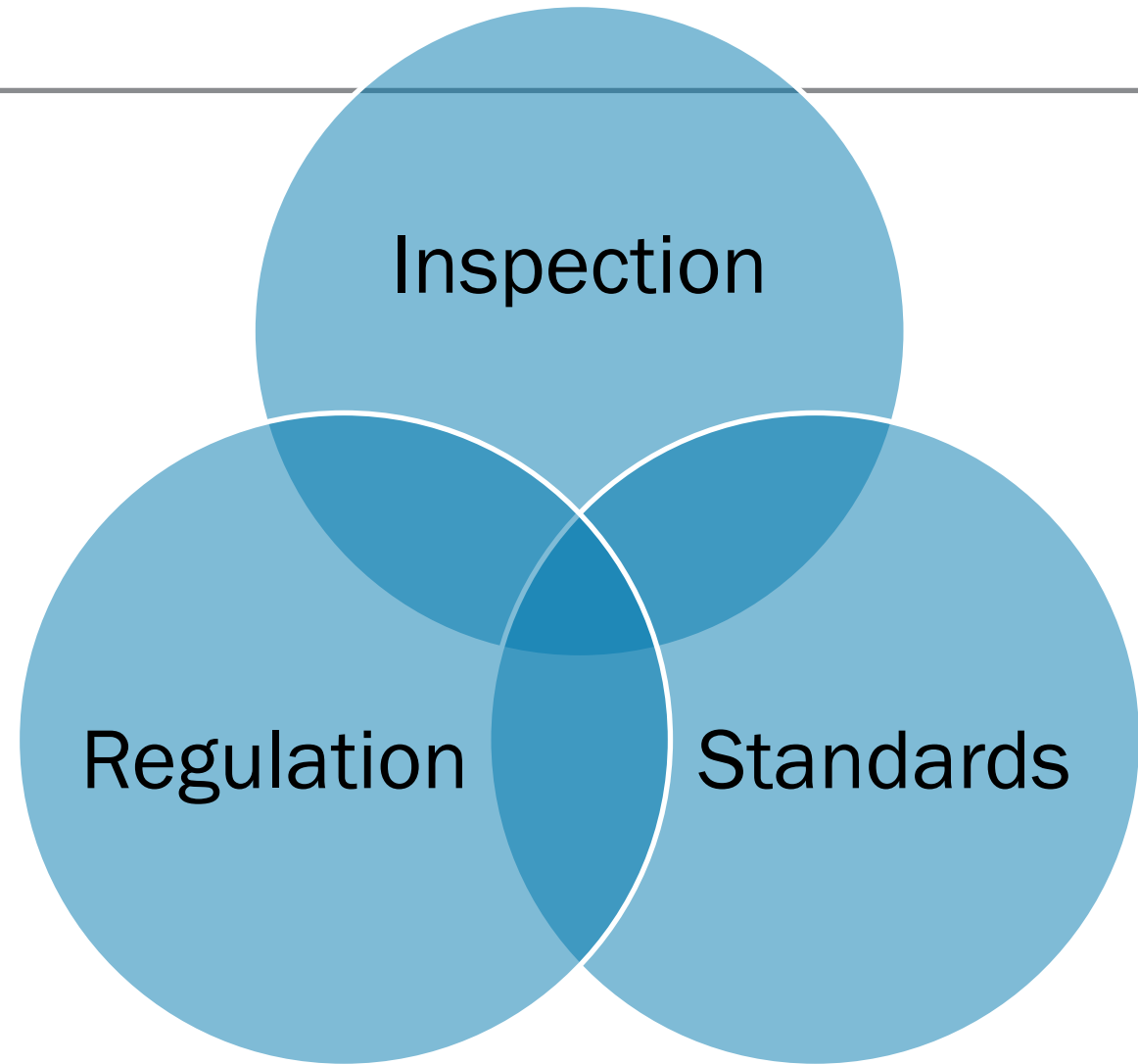
A photograph of two men in a modern office environment. The man on the left, who is bald and wearing glasses and a light blue button-down shirt, is pointing at a document on a wooden table. The man on the right, with short brown hair and wearing a white button-down shirt, is looking down at the same document. They appear to be in a collaborative discussion. The background shows office shelves and equipment, slightly out of focus.

WHAT IS A STATE-OF-THE-ART DAM SAFETY PROGRAM?

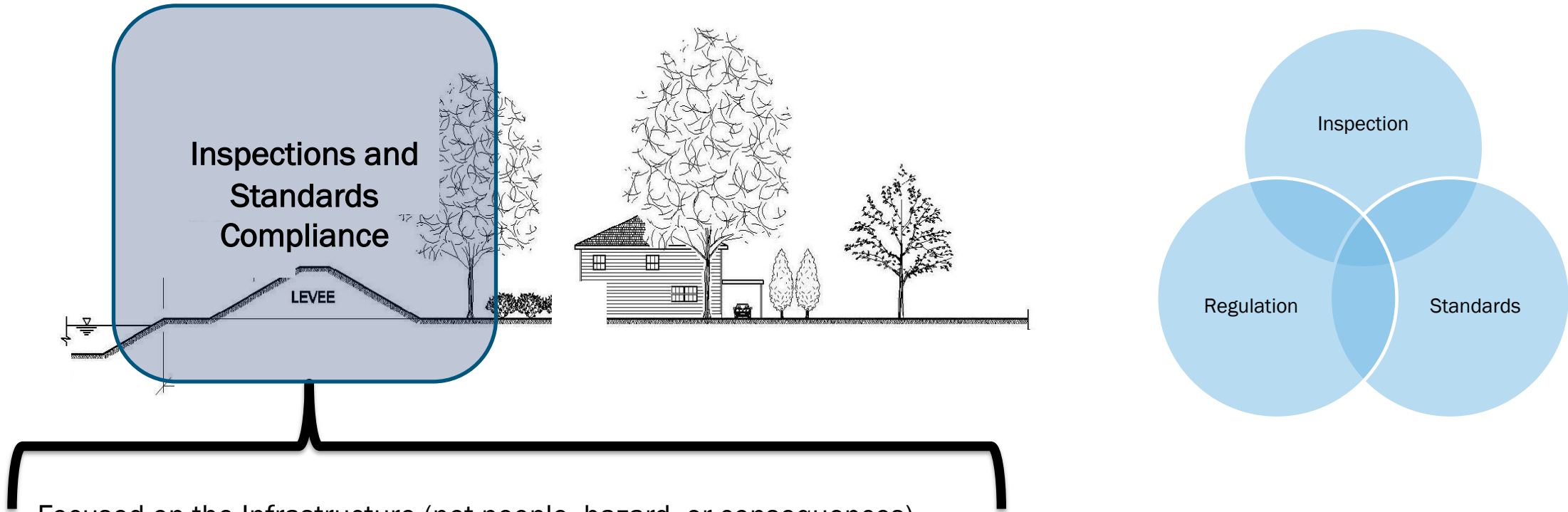
Lessons from Modern Dam Safety Programs

Traditional Dam Safety Program Focus (1968-2000)

- Compliance with Design Standards as a Measure of Safety
- Inspection and Monitoring for Performance Concerns
- Safety Assured by Regulation



Traditional View of Infrastructure Safety



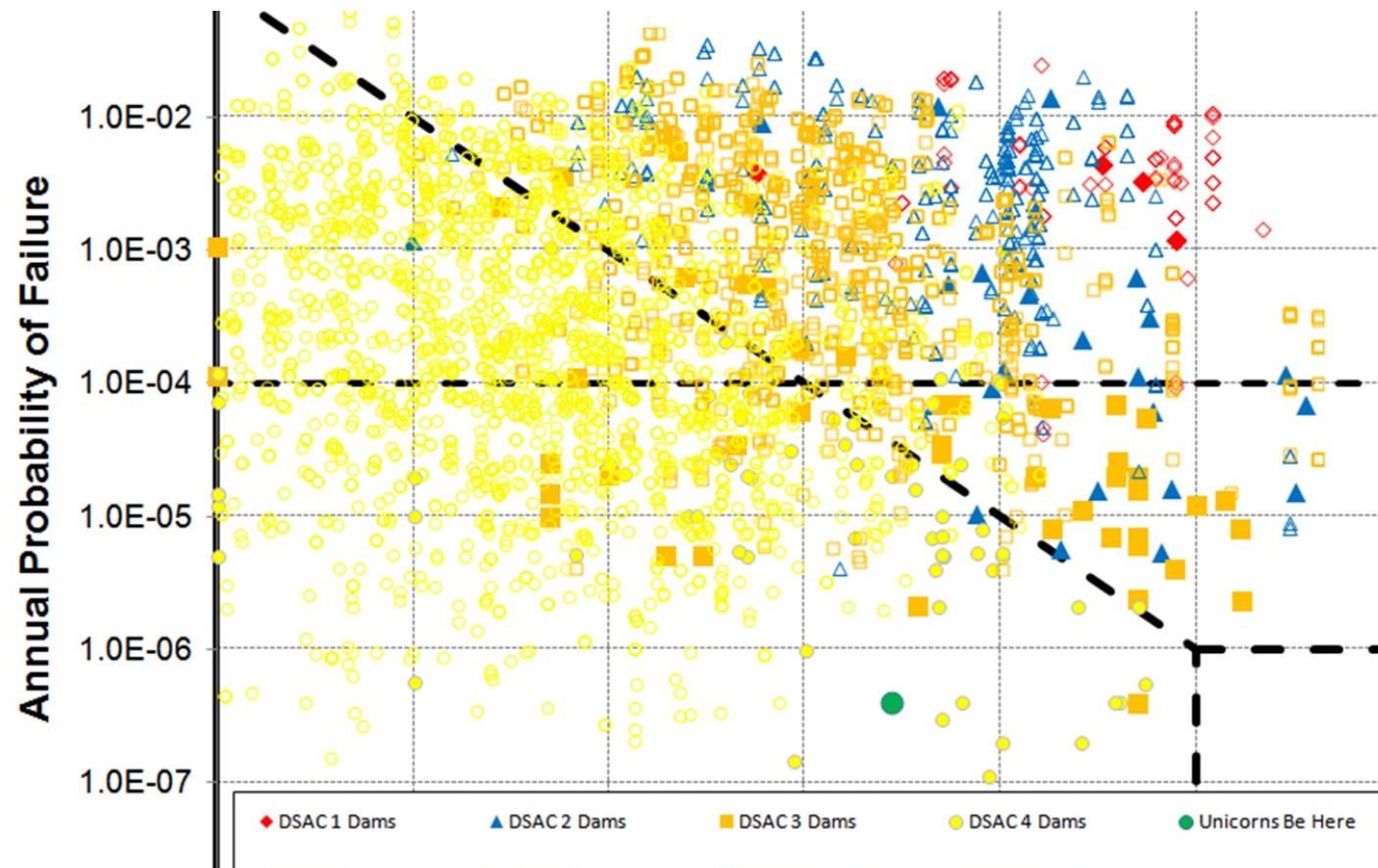
Focused on the Infrastructure (not people, hazard, or consequences)

Focused on How We Built Them, Not How They'll Perform (not integrated systems – think New Orleans)

Focused Compliance with Design Standards as a Measure of Safety, Assured by Regulation

This is what following standards only has resulted in...

- Huge Variation in Risk
- Over and Under Investment in Risk Management
- Wrong Priorities
- Poor Understanding
- Dynamics!



One Size Doesn't Fit All!

Some Limitations to Consistency of Standards Based Loading Conditions

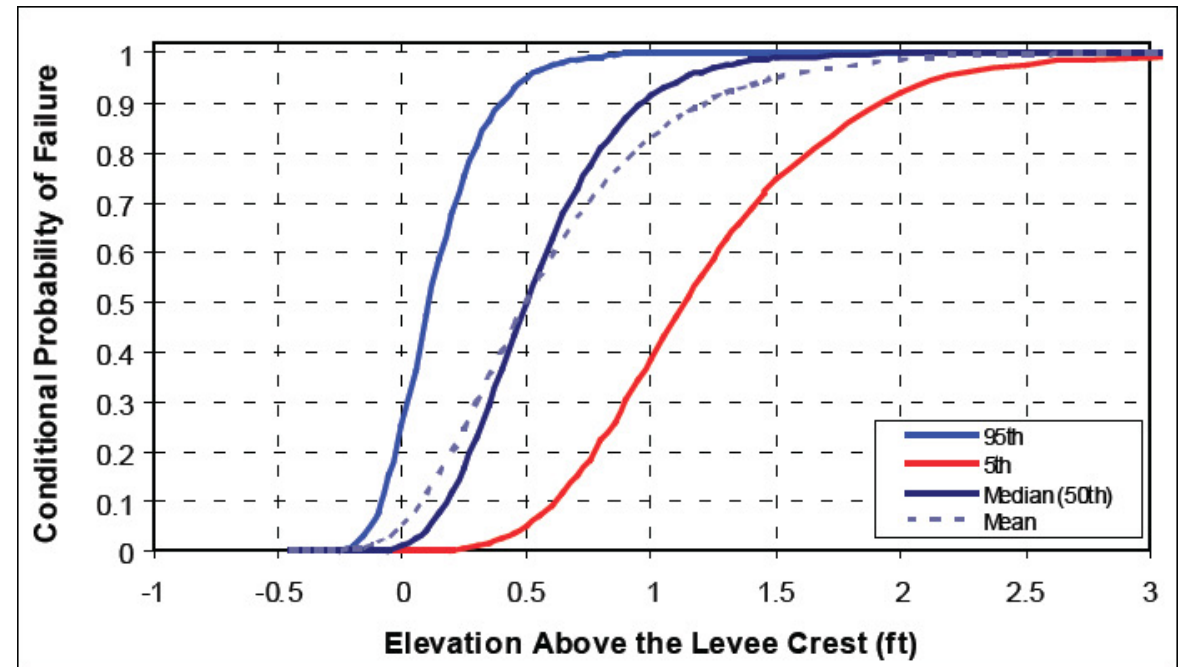
- Frequency of events not considered
 - Non-equality between loading conditions at a dam:
 - PMF frequency = $1/500,000$
 - MCE frequency = $1/5,000$
 - Non-equality between dams in a portfolio
 - PMF frequency = $1/1,000,000$
 - PMF frequency = $1/1,000$



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Some Limitations in Deterministic Stability Approach

- Likelihood of failure not fully considered
 - Meet or don't meet guidelines/criteria
 - For $F.S = 1.4$
 - Dam A – Probability of failure = $1/5,000$
 - Dam B – Probability of failure = $1/250$



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Some Limitations in Hazard Potential Classifications Approach

All high hazard structures require the same guidelines/criteria

Dam A – Estimated loss of life = 1

Dam B – Estimated loss of life = 10,000



Misconception About Standards and Dam Safety...

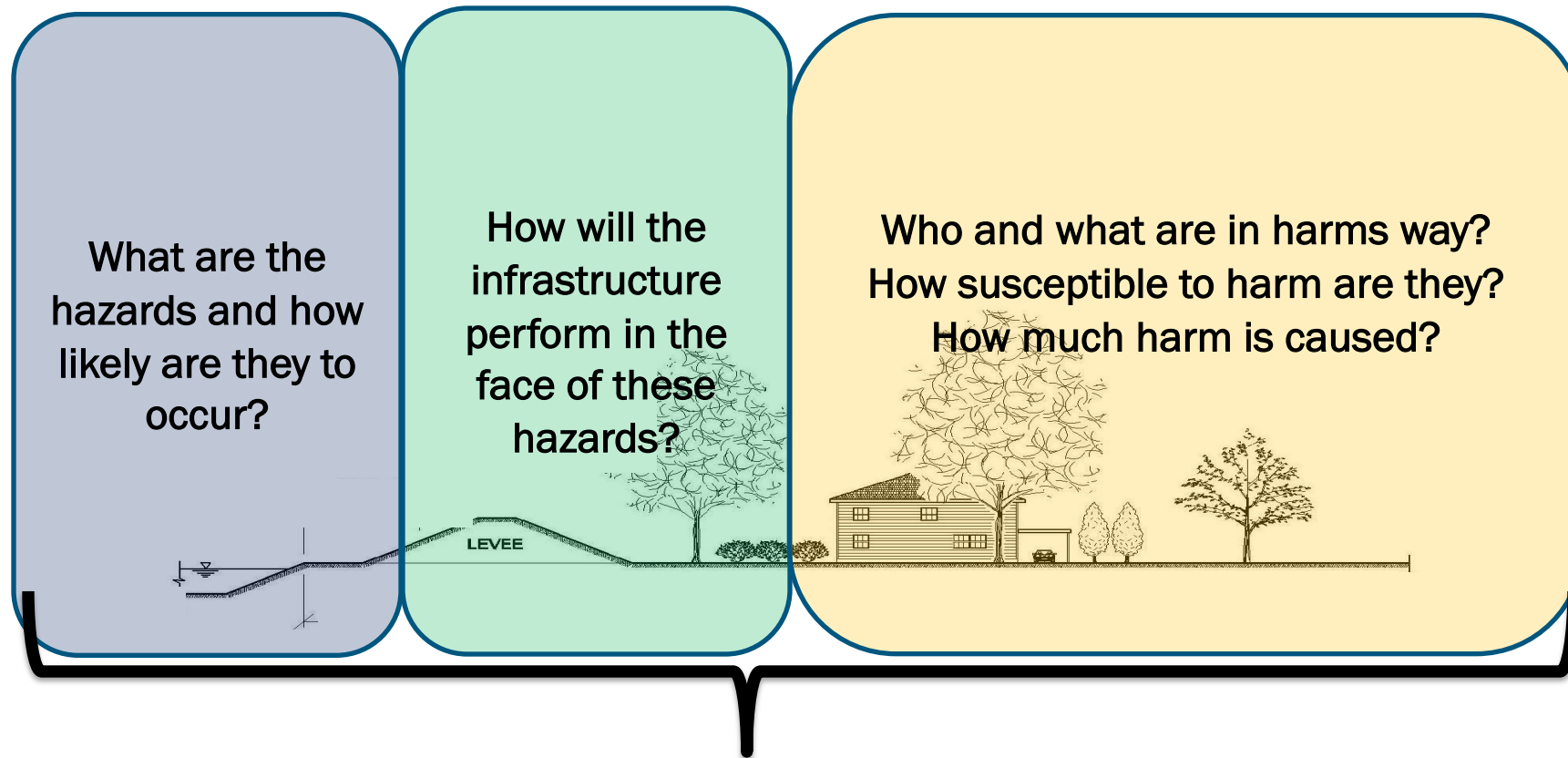
- Meeting standards = Safe (no failure)
- Meeting standards = Acceptable performance
- Meeting standards = No uncertainty
- Meeting standards = No more thinking required



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Risk Informed View of Infrastructure Safety

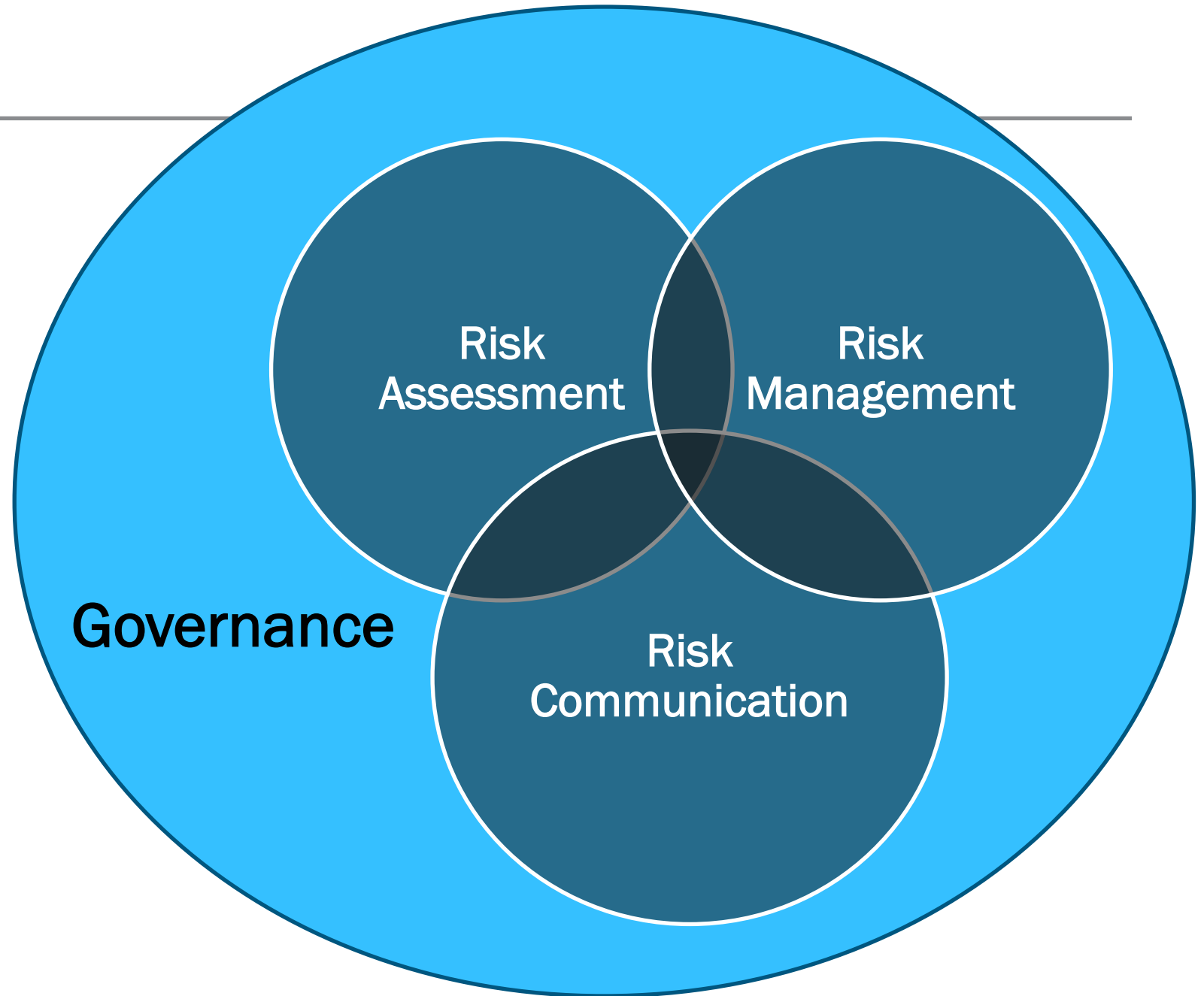
$$\text{Risk} = f(\text{Hazard}, \text{Performance}, \text{Consequences})$$



Modern Infrastructure Program: Focused on People, Performance, and Risks

Modern Dam Safety Program Focus (since 2000)

- Understand How Things Can Fail and the Risk Associated
- Risk Informed Decisions
- Sharing Responsibilities Via Improved Communication
- Governance: People, Process, & Policy



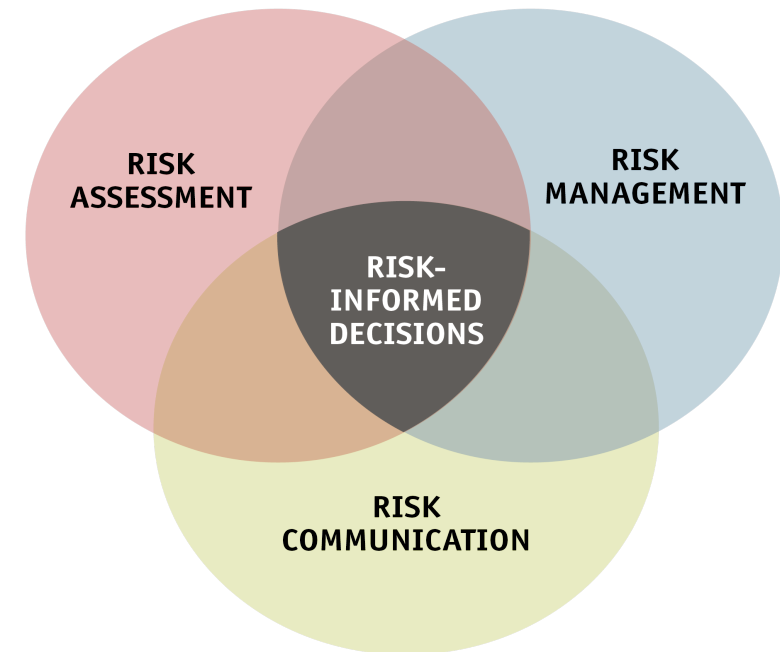
Why is a Strong Risk Framework Necessary?

- **Integration *is* Credibility:**

- Dam Systems and the Environments they exist in are Complex and Dynamic
- Problems that You Can Understand are Problems That Can Be Solved
- Clear Relationships Within Governance: Policies, Processes, and People/Organizations

- **Built for the Long Haul**

- Enduring Across Multiple Generations
- Adaptable to Evolving Practice, Science, Data, and Research



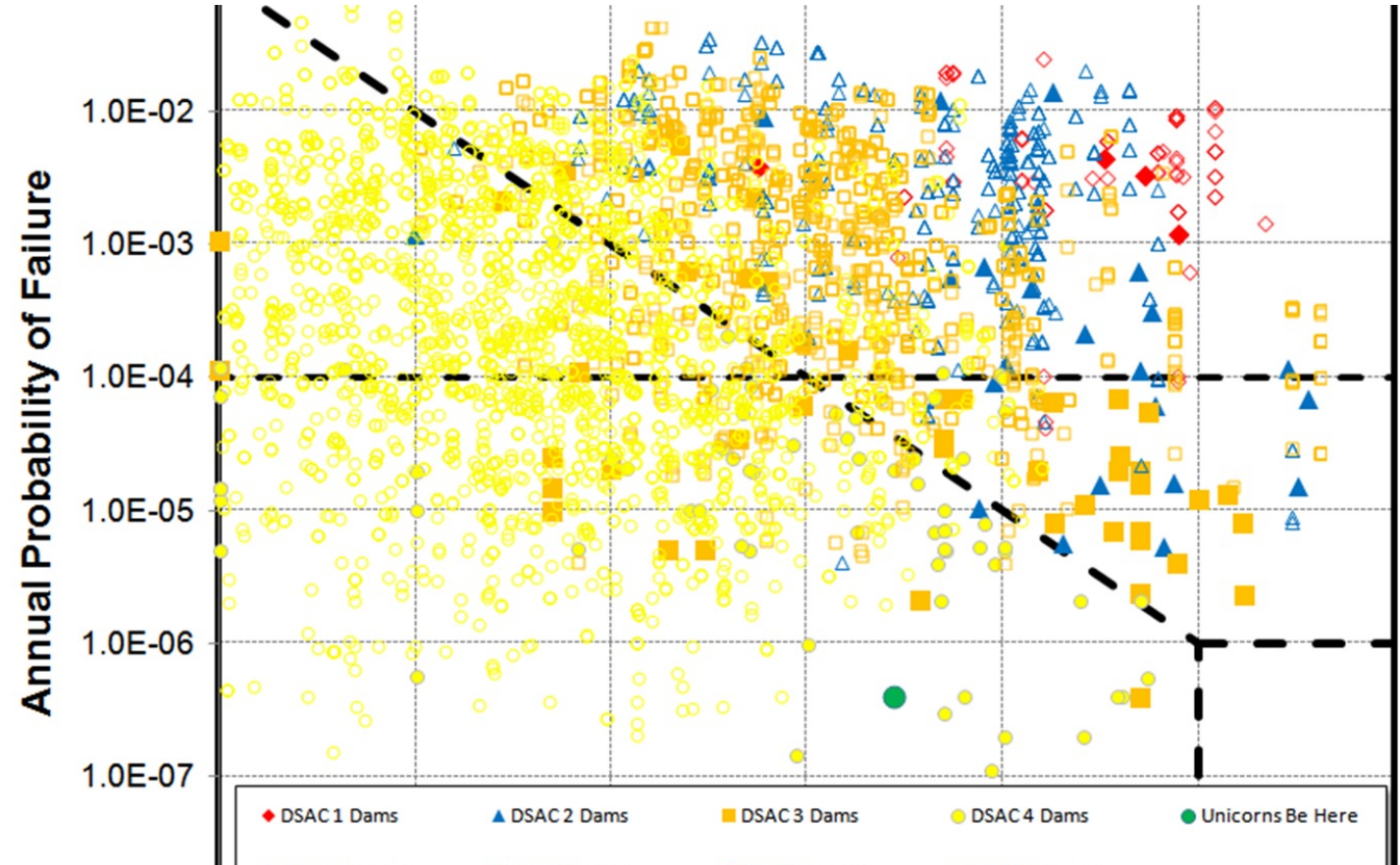
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Lessons on What Doesn't Work So Well...

Lessons from Modern Dam Safety Programs

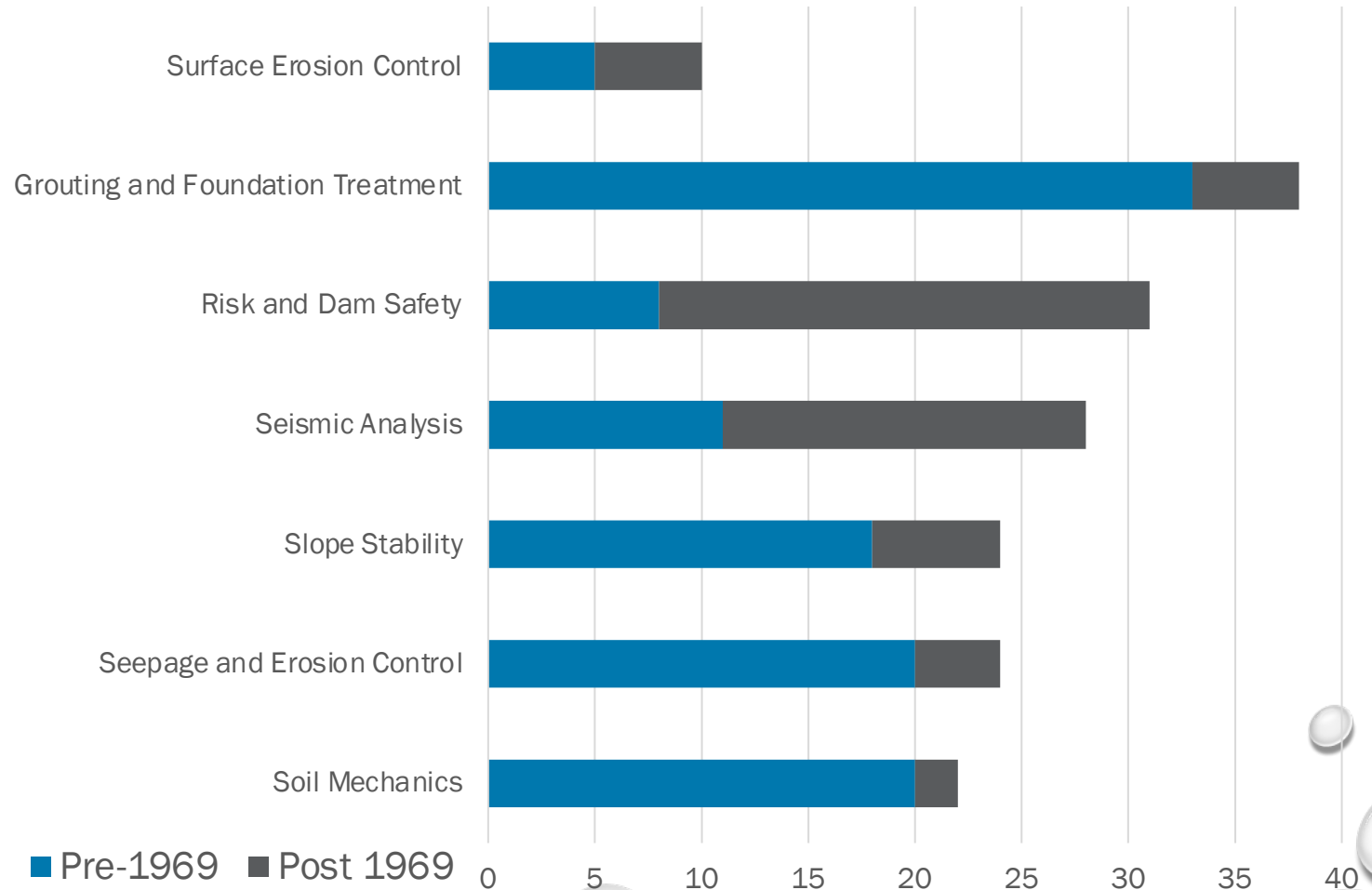
Relying on limit states and standards as a decision basis has resulted in this....

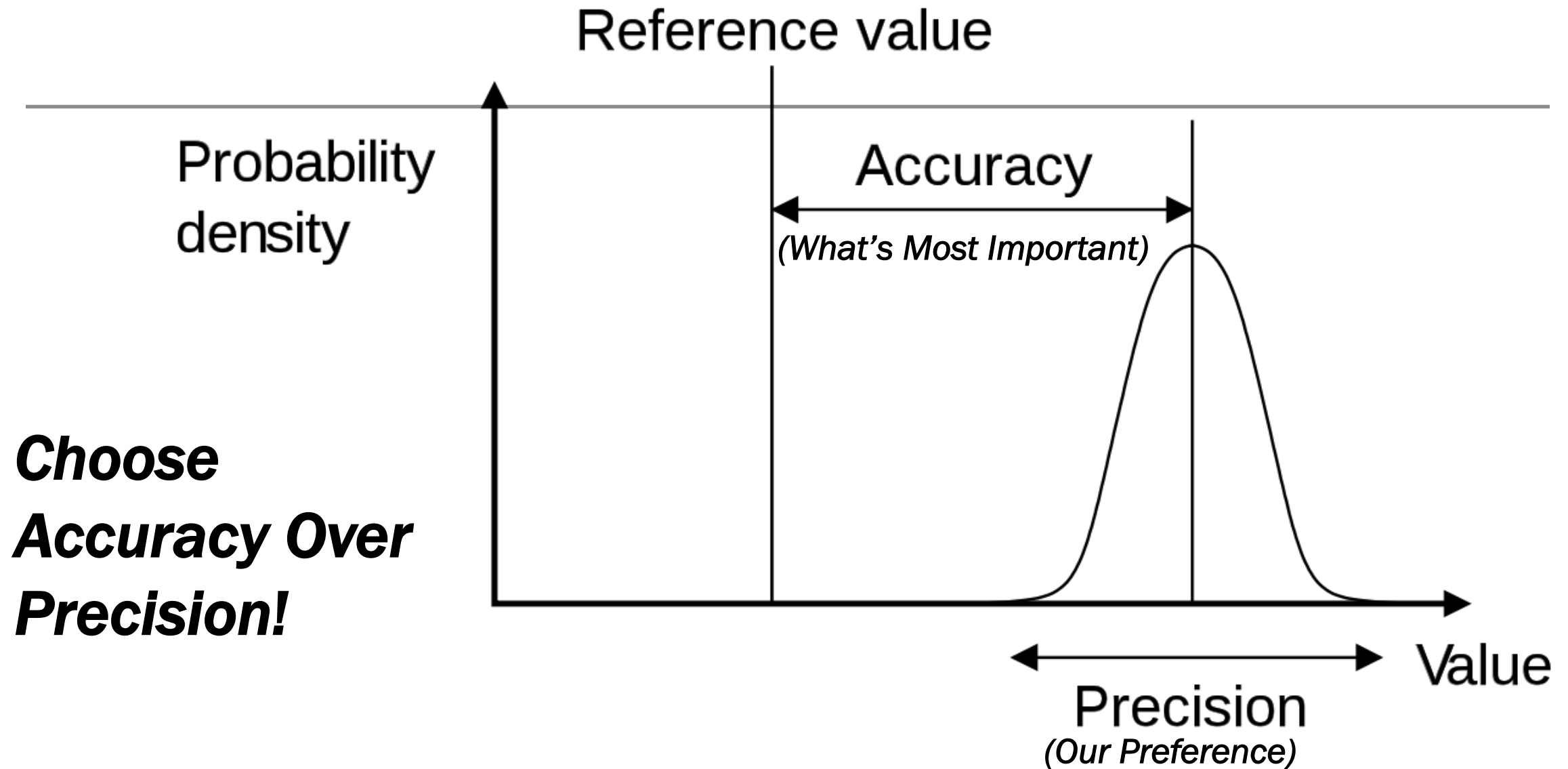


State of the Art Advancements In Geotechnical Design

**When Did Major
Advancements in Our
Profession Occur?**

**65%
Before
1969**





"I'd rather be approximately right than precisely wrong."

J.M. Keynes

Uncertainty Paradox

- Engineers Believe Decision Makers Demand Precision and certainty so We ***DOUBLE DOWN*** on what we know (and ignore the rest)

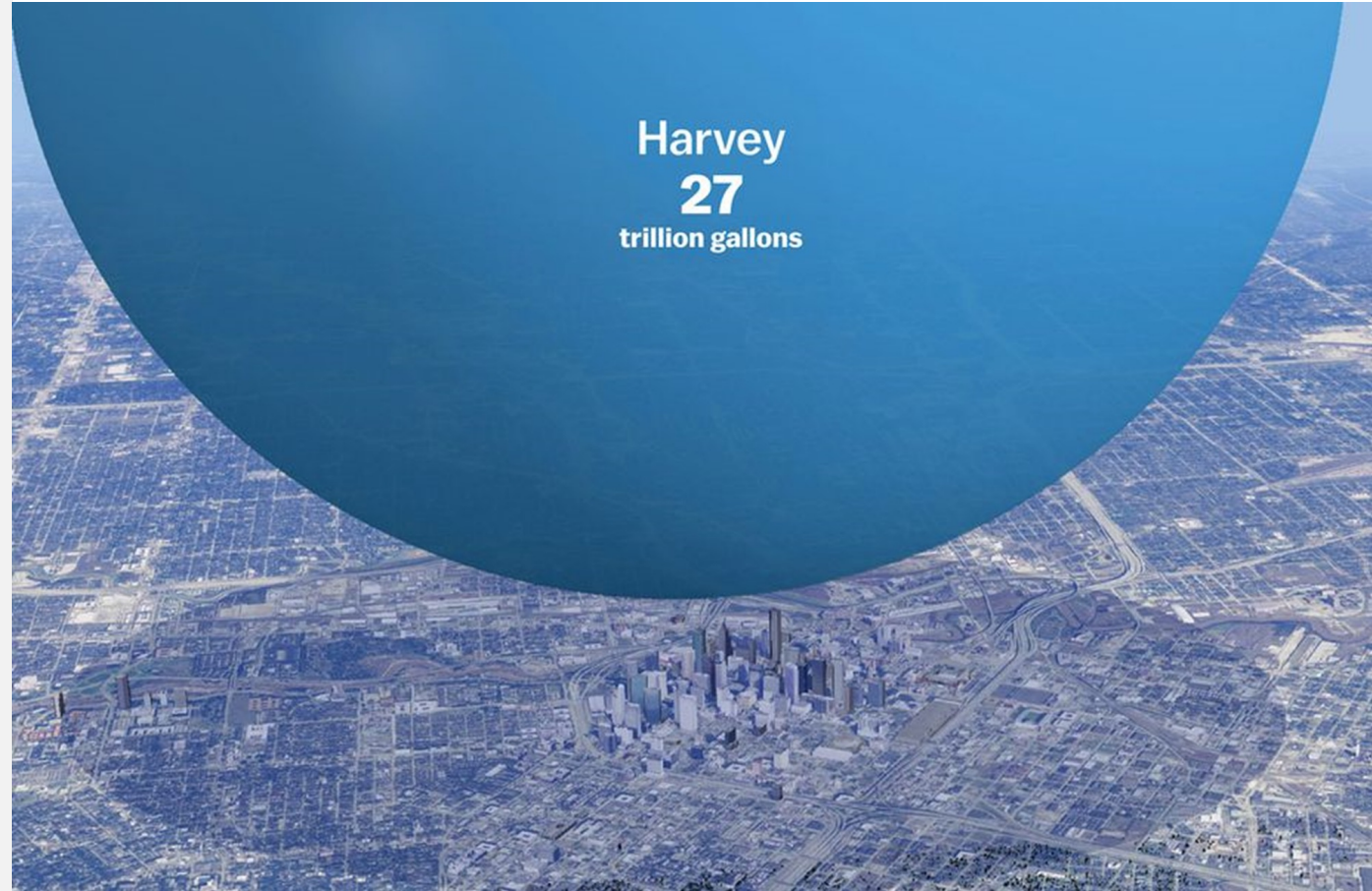


Telling Instead of Showing

Lessons on What Doesn't Work Well

“Houston, Texas recorded the largest Rainfall on record within the continental United States. Over 60 inches of precipitation in 48 hours. That’s when the gage broke.”

an H&H friend of mine...



The Volume of Water that Fell on Houston
During Hurricane Harvey

Lessons on What is Effective...

Lessons from Modern Dam Safety Programs

More Data
More Precision
The Uncertainty
Paradox

Research
Education
Studies
Science
Professional Journals
Case Histories
Experience
Expertise

10% Knowledge

90% Knowledge
Uncertainty

**When
Uncertain,
Leverage
Science First**

Lessons on What Works Well

Understanding How Things Can Fail and the Consequences

Lessons on What Works Well

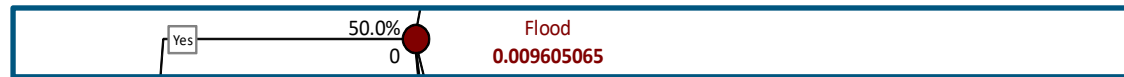


Challenger Explosion, 1986

Standards Based Understanding of Risk

$$FS_{GS} = 1.0$$

Based on lab data, specific loading



Is it safe?

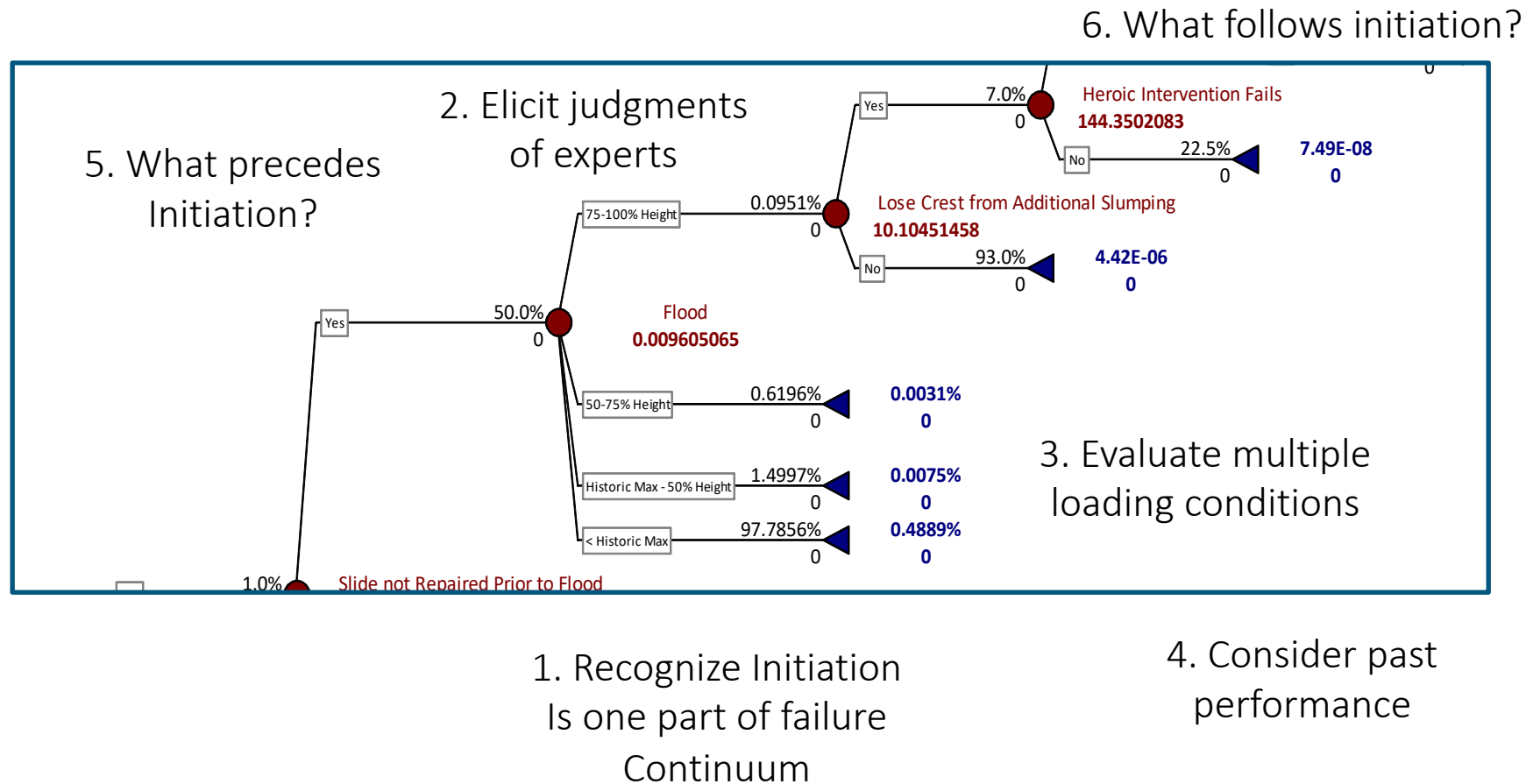
How confident are you?

What should you do?



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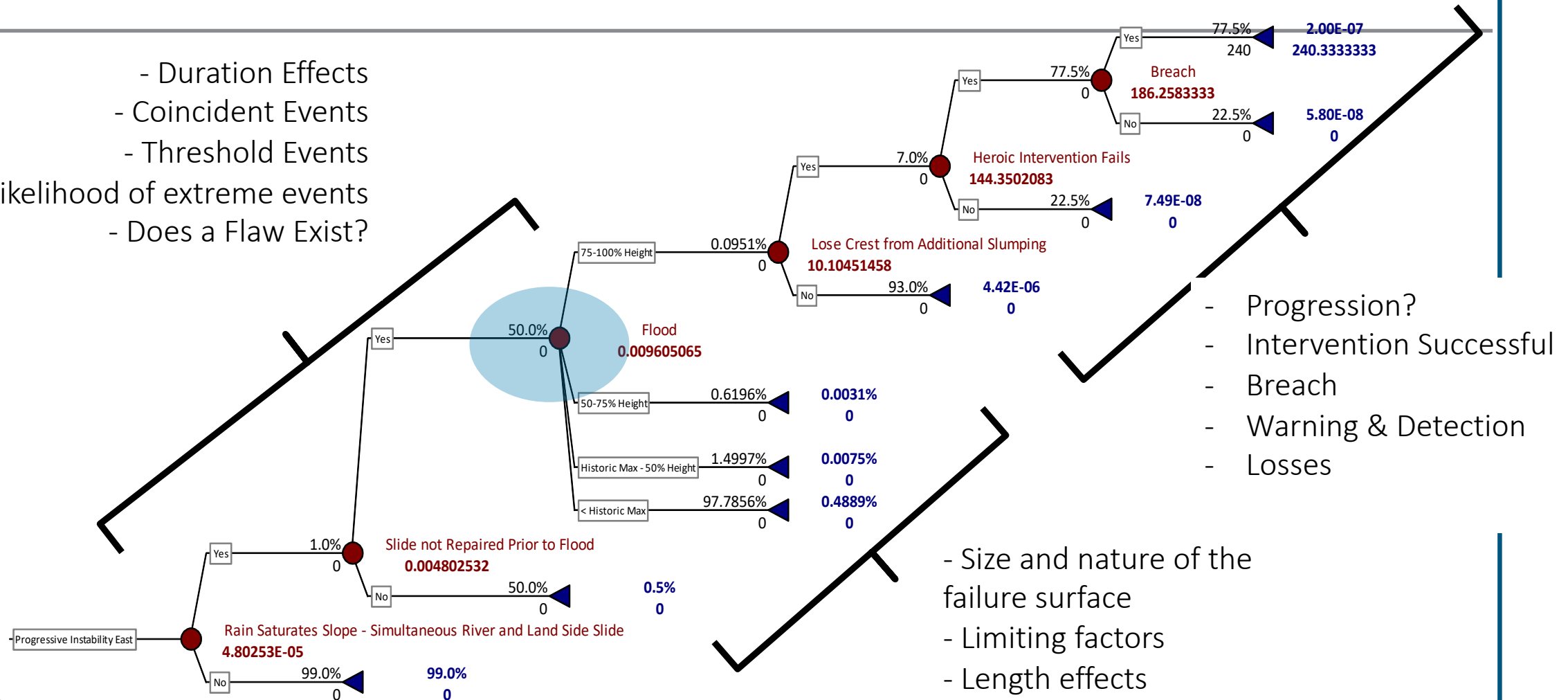
Improving the Understanding of Risk



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Quantitative Understanding of Risk

- Duration Effects
- Coincident Events
- Threshold Events
- Likelihood of extreme events
- Does a Flaw Exist?



- Progression?
- Intervention Successful
- Breach
- Warning & Detection
- Losses

- Size and nature of the failure surface
- Limiting factors
- Length effects
- Uncertainty in Materials
- Case Histories & Models

Nation

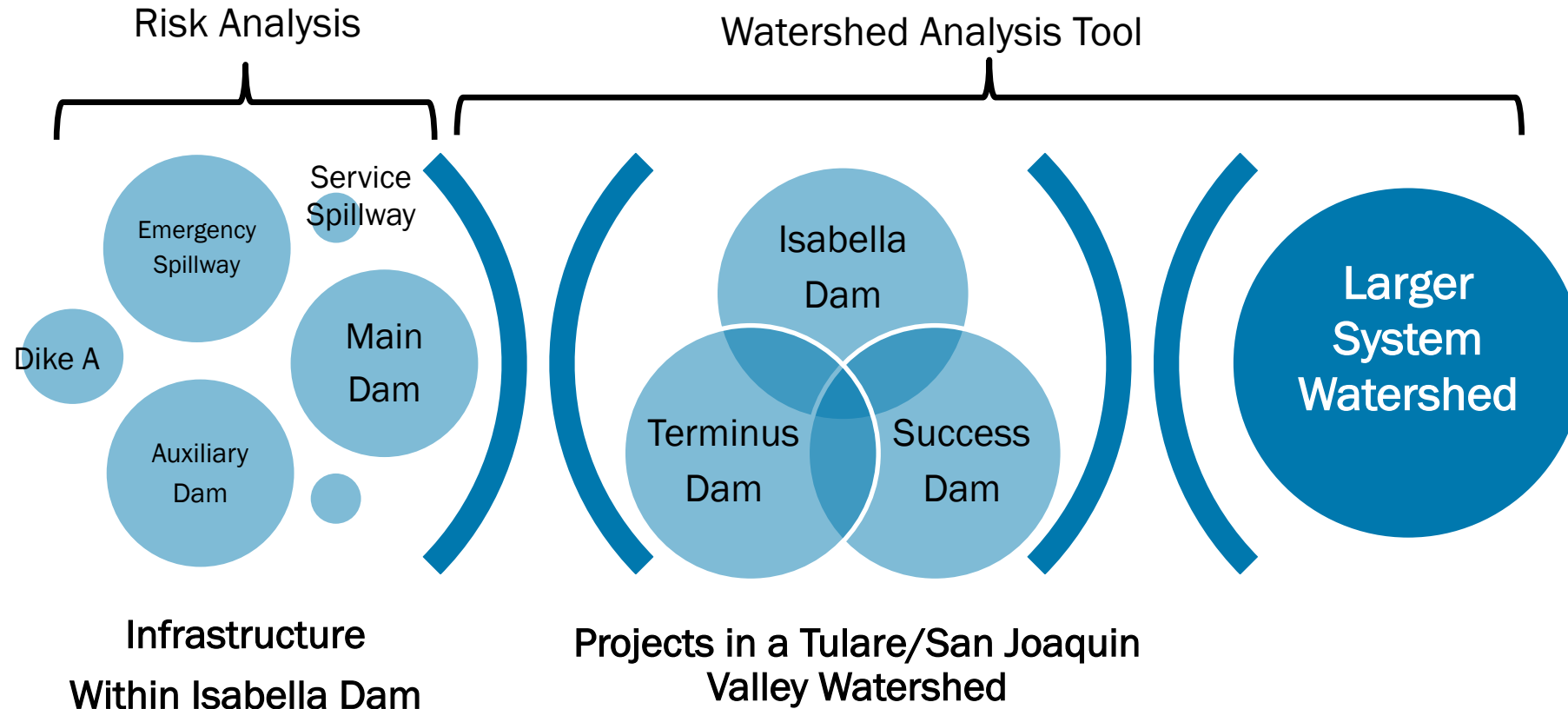
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Lessons: System Effects

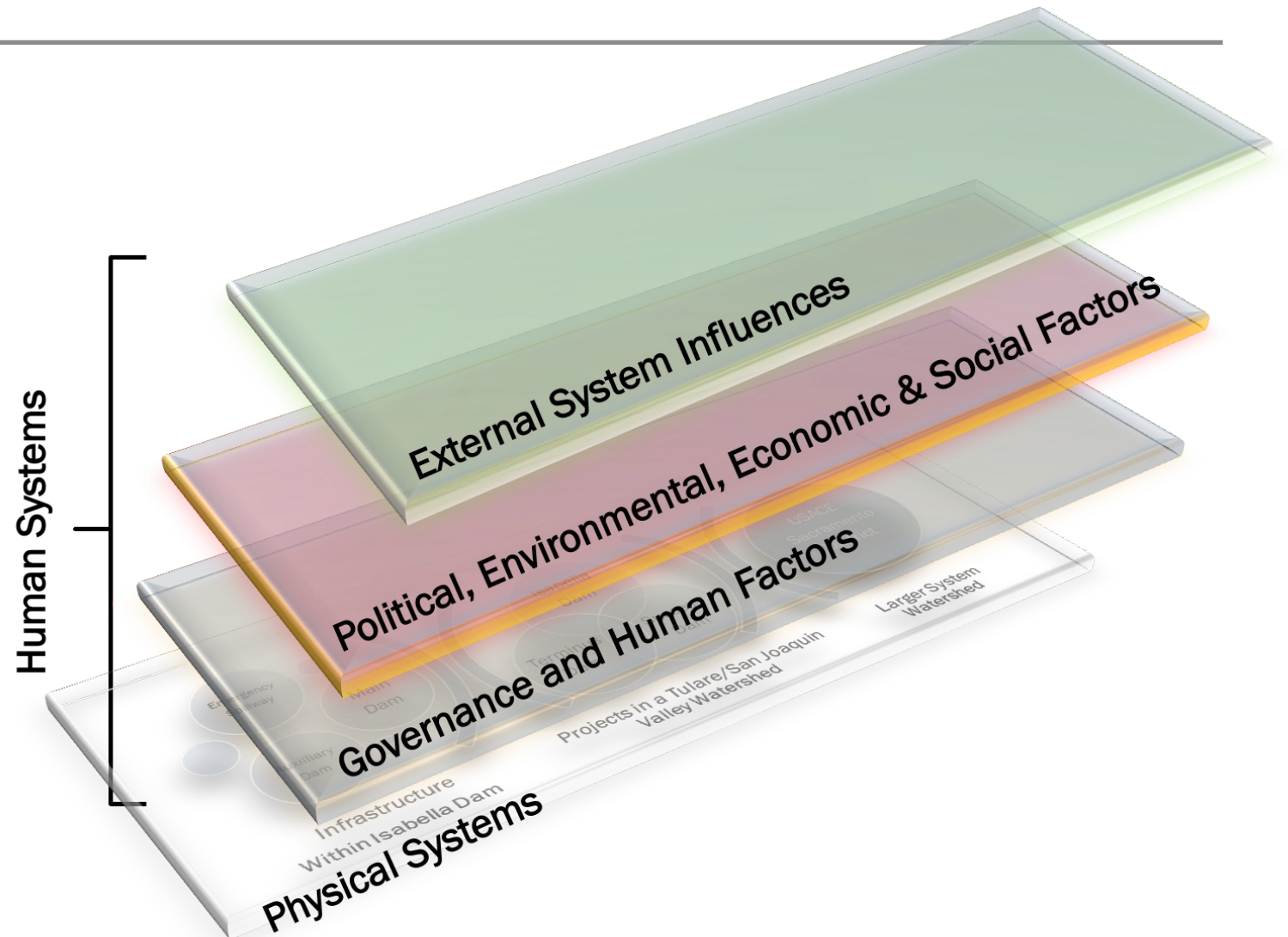
- Identify Inter-Relationships
- Simplifying Assumptions Appropriate
- Quantify When Appropriate



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Lessons: Human Factors

- Complex Interactions Can Increase Risk and Uncertainty
- Errors, Biases Are Real
- Understand the External Influences on your Project
- ***Good Governance Mitigates Most Human Factors***



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Lessons: Extreme Events

- Probabilistic Methods Important to Decision Making, Particularly in Urbanized Areas
- Extreme Events Happen!
- Pay Attention to Gate Reliability



2020 Fires, San Francisco, California
Billion Dollar Disasters



Lessons: Independent Peer Review

Change Practice

The “no fail” branch in some event trees can transition to failure in other failure modes

Avoidance and Consideration of Large Damage States can transfer risk within a system.

Sustain Practice

Independent Review and Challenge of Past Assessments is Necessary

Considerations of Systems and Human Factors Is Consistent with (and already a part of) Risk Informed Practice

Something to think about...



Reference: Ignacio Escuder-Bueno & Eric Halpin (2016):
Overcoming failure in infrastructure risk governance
implementation: large dams journey, Journal of Risk Research

Why is Risk Embraced in Concept But Not in Practice?



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Thank You



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