Quantitative Risk Analysis

FEDERAL ENERGY REGULATORY COMMISSION
OFFICE OF ENERGY PROJECTS
DIVISION OF DAM SAFETY AND INSPECTIONS

Risk

Risk = Probability of Failure x Consequences

Probability of Failure = Probability of Load x Structural Response Given Load

What is Quantitative Risk?

- Risk becomes quantitative when procedures are used to fully define the risk quantities.
- Event trees are used for each step of the PFM event tree.
- As needed, each step is assigned a probability density function and the results are combined into an annualized probability of failure for a particular failure mode.

Quantitative vs Qualitative Risk

- Probabilistic loadings rather than frequency estimates
- Fragility curves rather than general estimates of likelihood of failure
- Expert elicitation for assigning probabilities rather than team-based qualitative approach.
- Defined consequence information vs partially estimated.

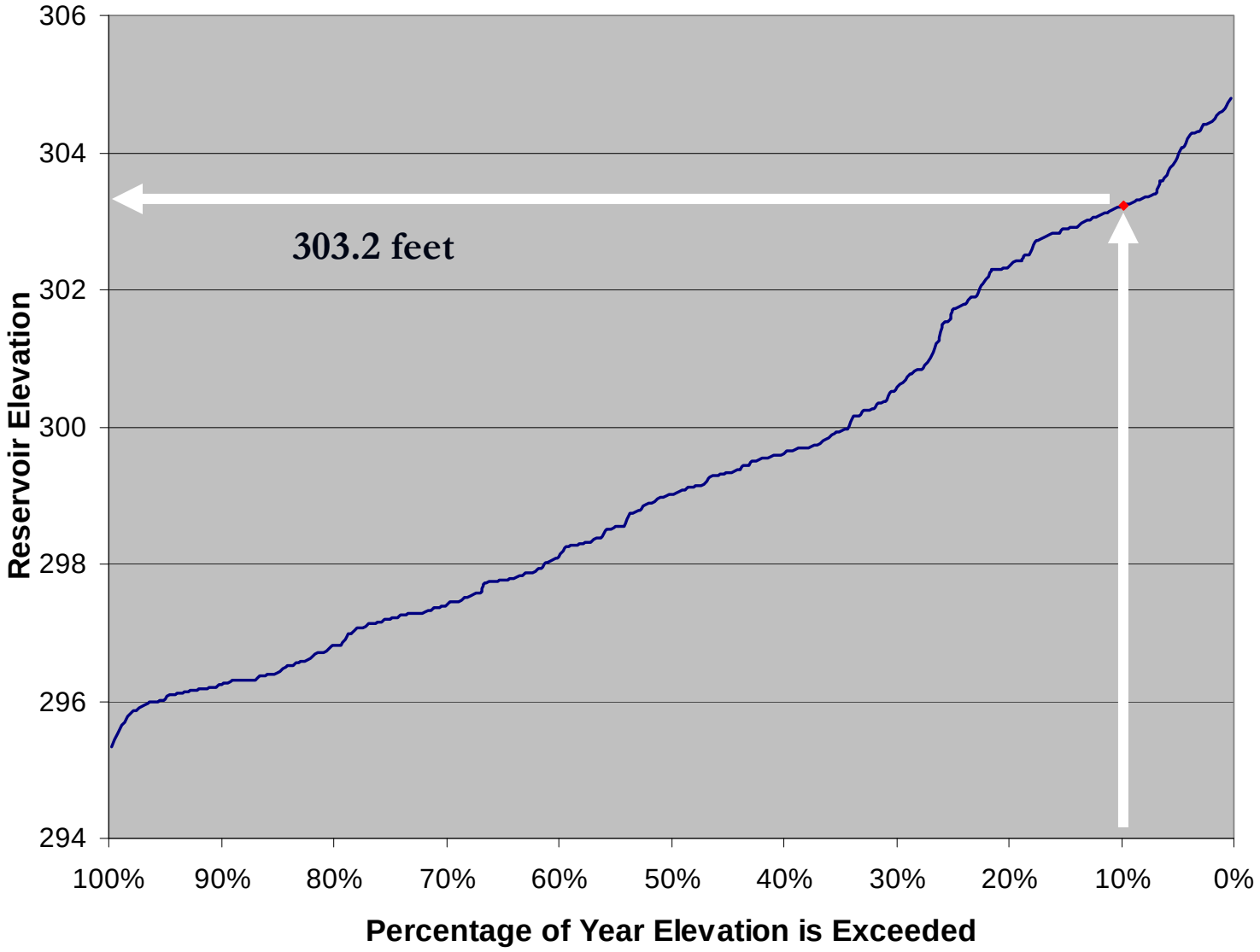
Probability of Load

- Probability of Load
  - Static Loading = Reservoir Elevation Frequency Curve
  - Earthquake Loading = Probabilistic Seismic Hazard Analysis (PSHA)
  - Flood Loading = Rigorous Flood Frequency Analysis (FFA)

Reservoir Exceedance Curves

- Reservoir Elevation key loading parameter for evaluating potential failure modes
- Influences static PFMs as well as potentially changing consequence information, i.e., PLL.

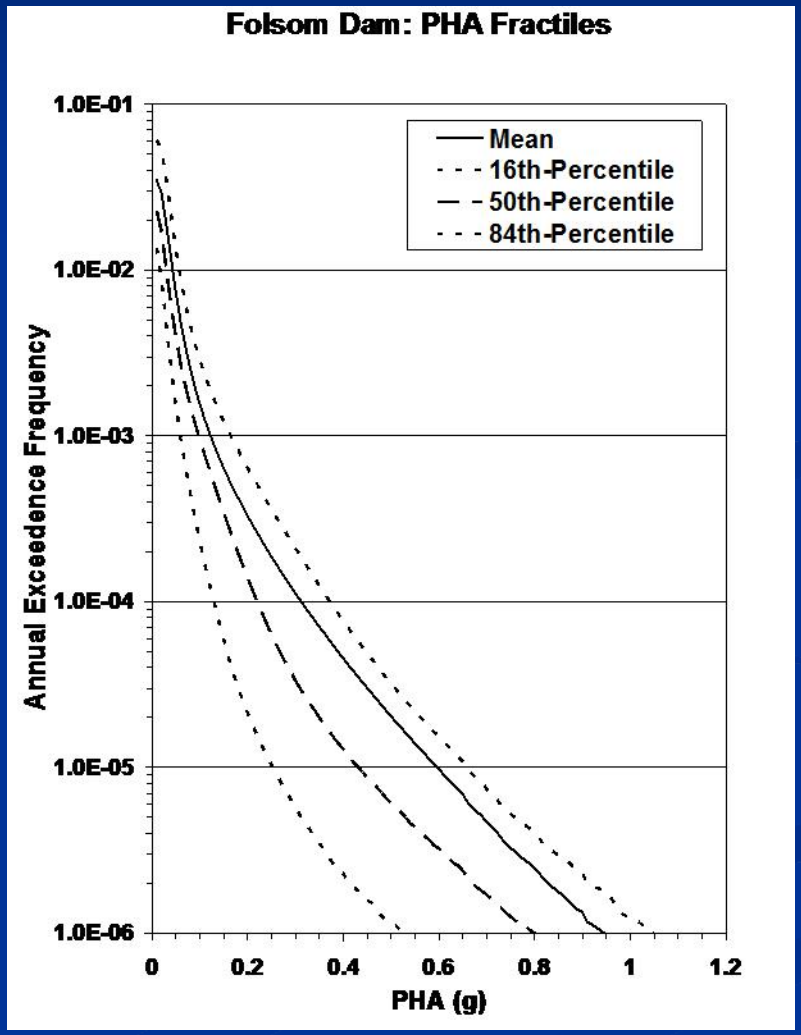
Reservoir Exceedence Curve



Probabilistic Seismic Hazard Analysis (PSHA) Curve

- PSHA methods - used in the Western United States (CA) for many years
- Techniques are well known
- Costs may be similar to deterministic analyses if the seismic source zones are well known and characterized
- Costs may be significantly higher if they are not well known or in areas without any previous studies

Probabilistic Seismic Hazard Analysis Curve



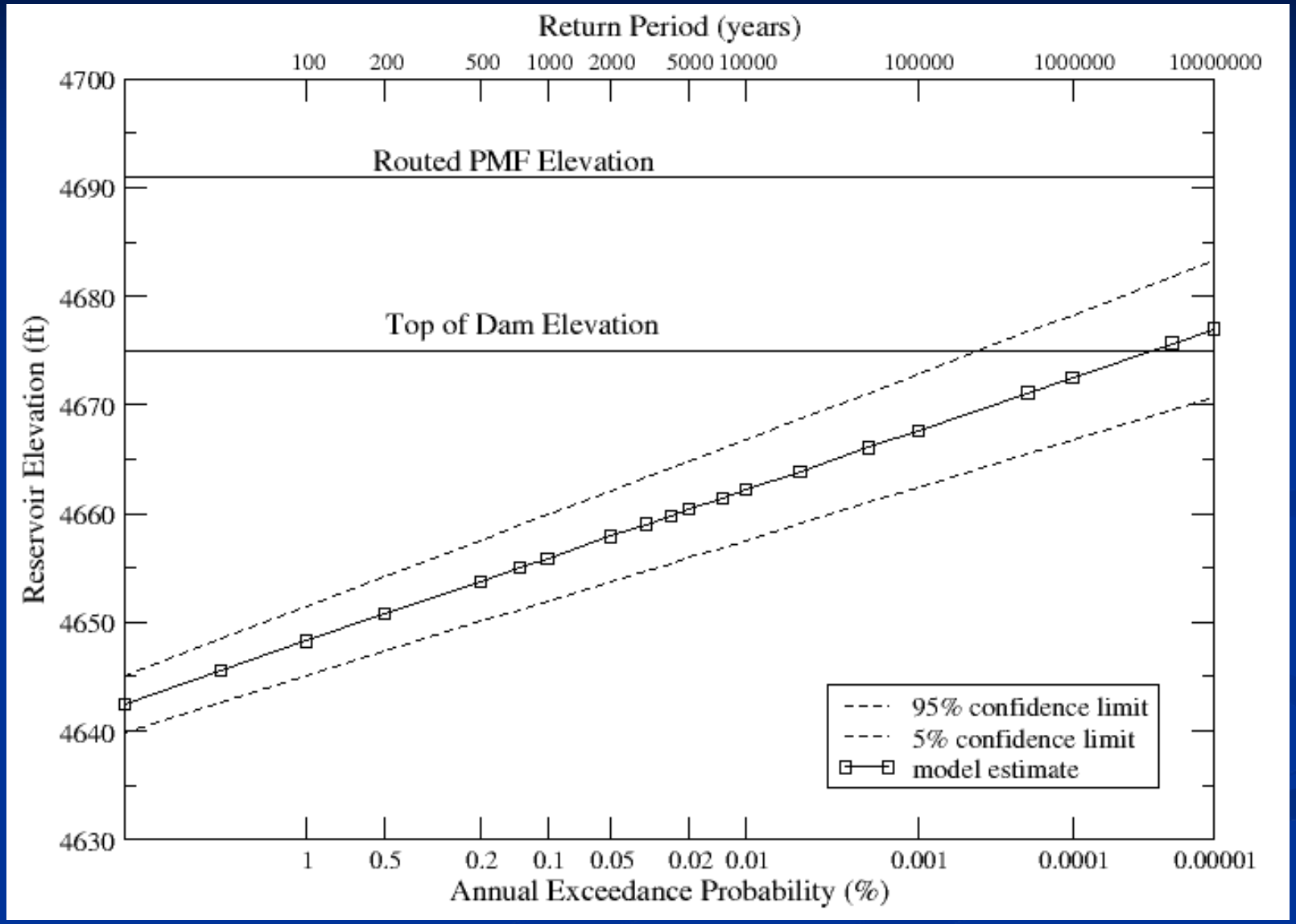
Flood Frequency Analysis (FFA)

- Reclamation has a fully developed program for calculating the FFA
- Discussed in Guidelines for Evaluating Hydrologic Hazards, June 2006, US Bureau of Reclamation
- The method is scalable in that it encourages use of simpler methods until more rigorous methods are needed.

Flood Frequency Analysis (FFA)

- FFA generally includes more than one method as follows:
  - Rigorous analysis of floods in the historical range
  - Simple scaling methods
  - Paleo studies to:
    - Find a physical range of floods that have not been exceeded or floods that have been at least so large in a certain time range.
    - Paleo studies often use 2-dimension flow analyses to calibrate these floods
  - Regional precipitation analyses and stochastic models to predict floods out to the extremes

Reservoir Elevation Frequency Curve



Hydrologic Hazard Curve

from Reclamation Best Practices

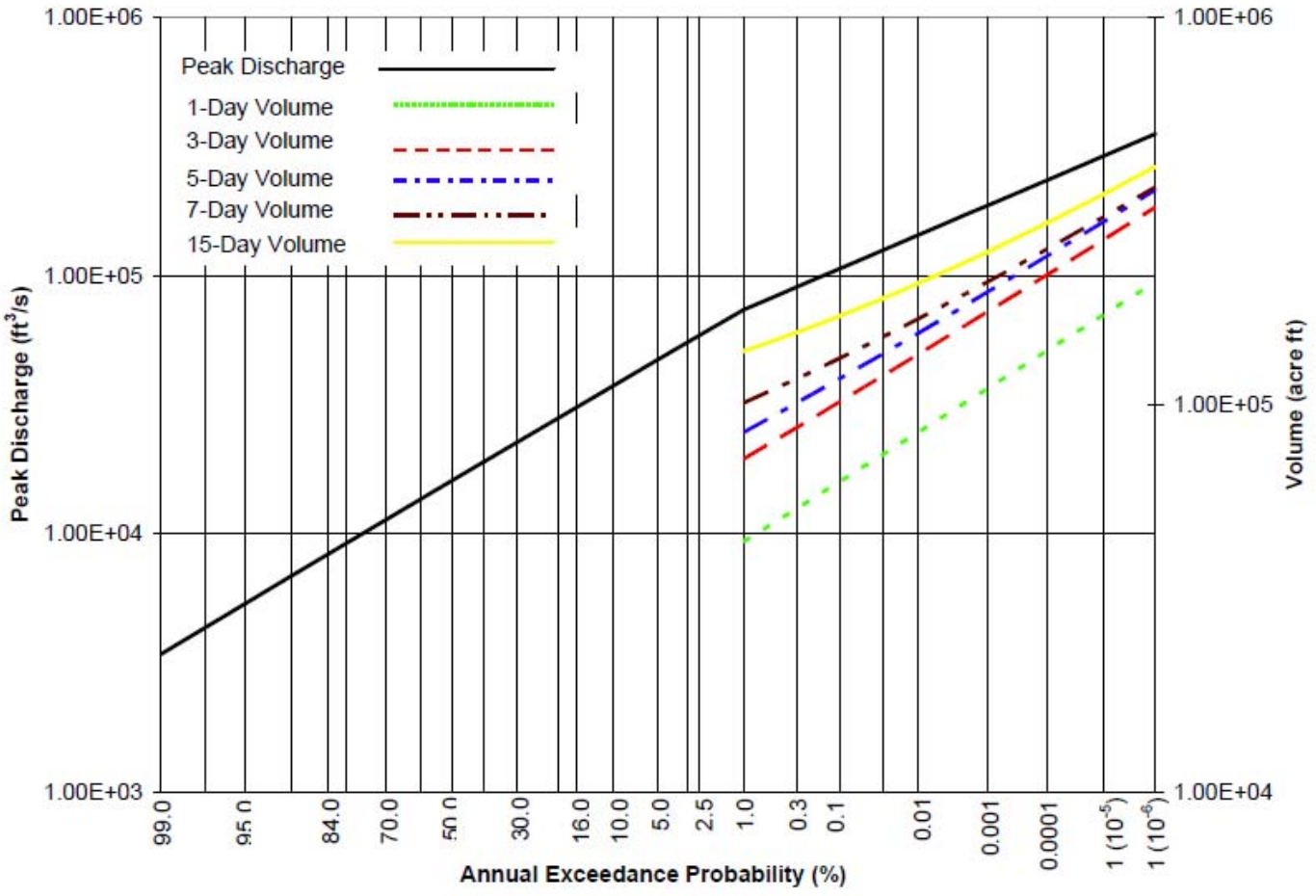
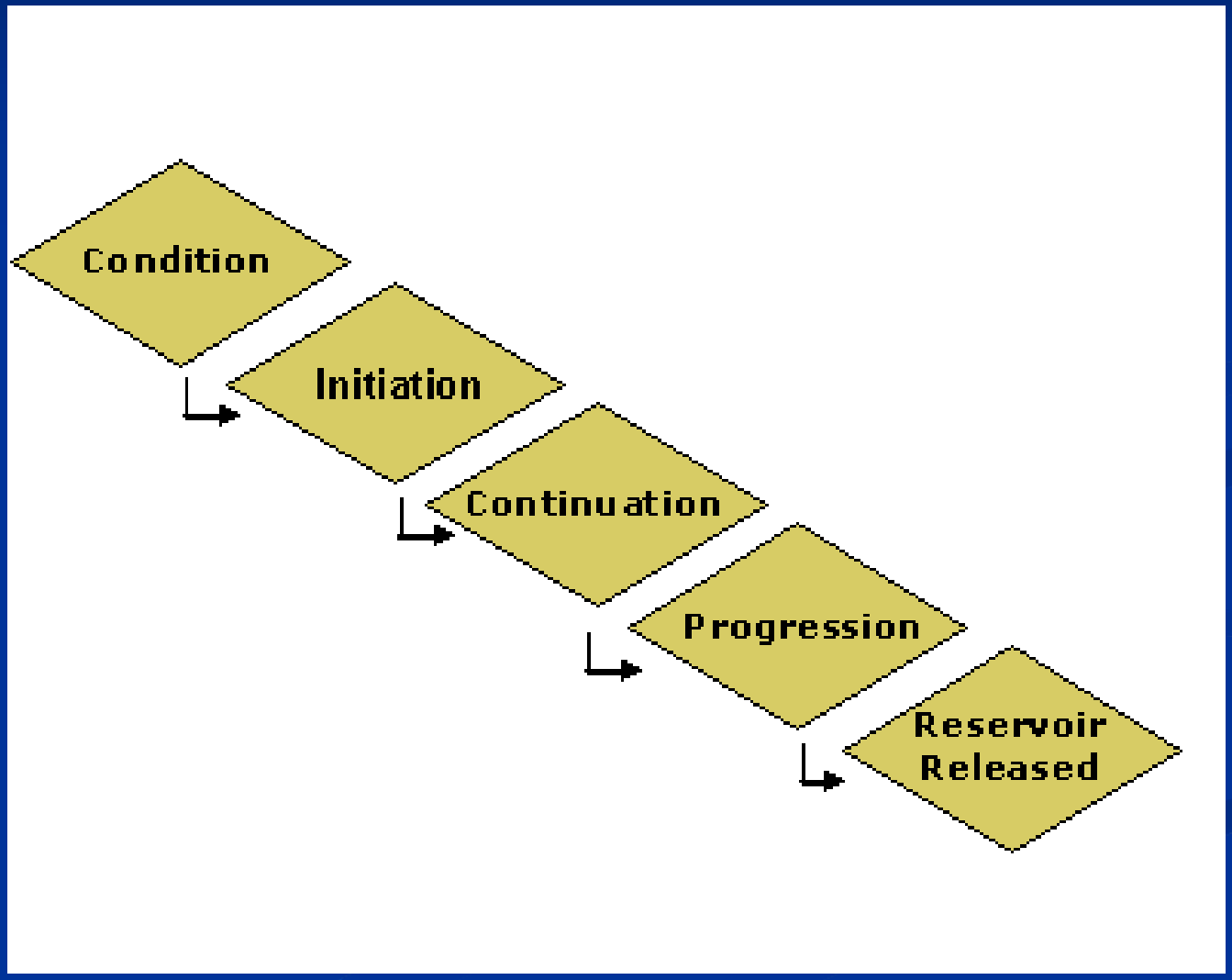


Figure 3-2.—Example hydrologic hazard curve.

Event Trees

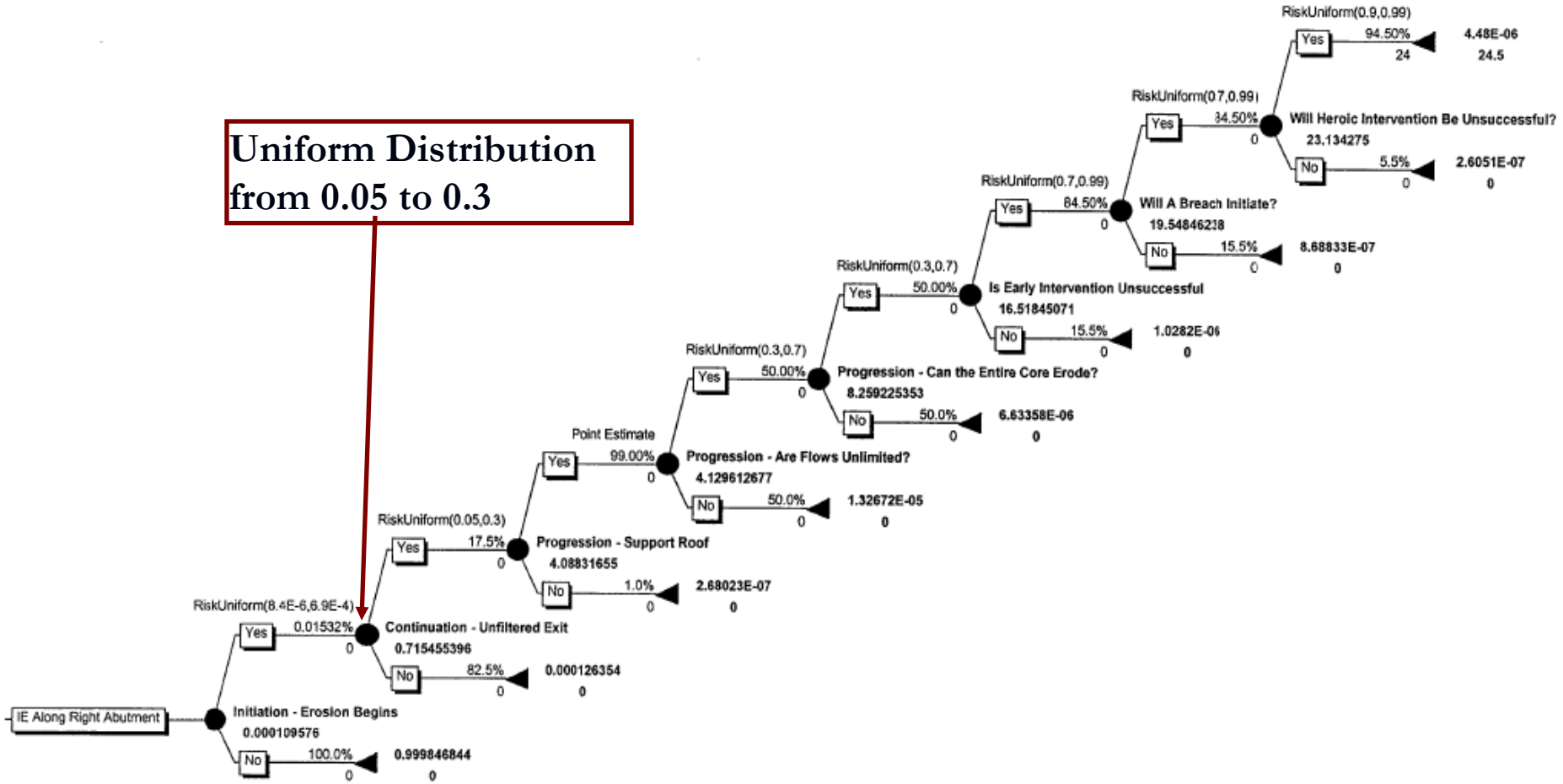

Condition
Initiation
Continuation
Progression
Reservoir Released

Internal Erosion Event Tree Description

from Reclamation Best Practices

- ↳Reservoir at or above threshold level
- ↳Initiation – Erosion starts
  - ↳Continuation – Unfiltered or inadequately filtered exit exists
    - ↳Progression – Roof forms to support a pipe*
    - ↳Progression – Upstream zone fails to fill crack
    - ↳Progression – Constriction or upstream zone fails to limit flows
      - ↳Intervention fails to prevent "break-through"
- Dam breaches

- *Node eliminated for Progressive Erosion



	Min	Max	Mean
Overhangs over entire path	0.005	0.02	0.0125
Core settles continuously	0.008	0.05	0.029
Void large enough	0.3	0.7	0.5
Core material begins to erode	0.7	0.99	0.845
	8.40E-06	6.93E-04	1.53E-04

FIGURE 9 – Static Event Tree for Internal Erosion Along the Right Abutment Overhangs

Uncertainty/Confidence

- Many types of uncertainty, but two main types are used:
  - Random uncertainty (aleatory)
  - Model and measurement uncertainty (epistemic)
- Random uncertainty is the variability of the natural world
- Model uncertainty is the result of how different analysis models might describe reality
- Measurement uncertainty is our inability to accurately know all relevant data.

Uncertainty/Confidence

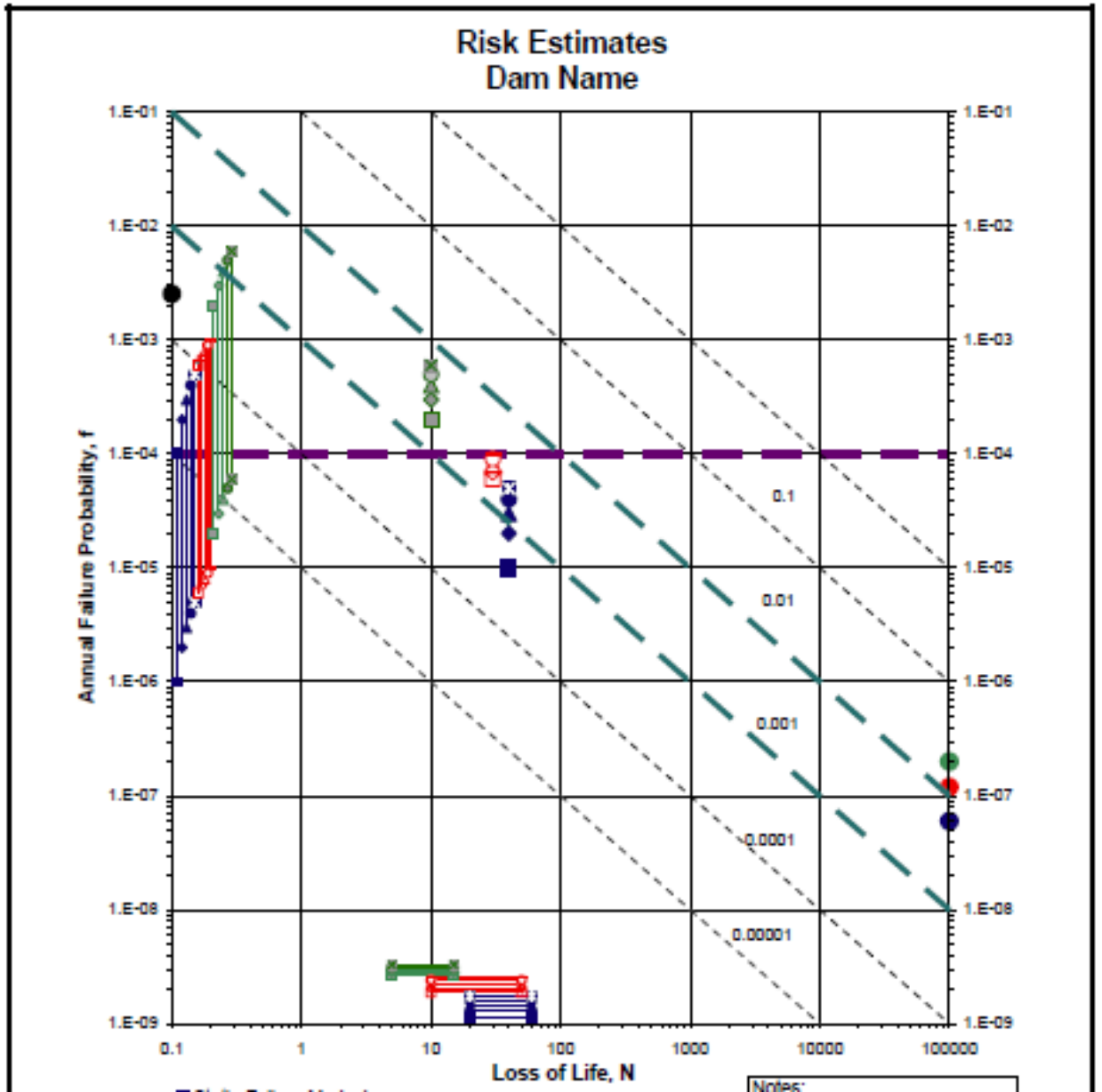
- Uncertainty can be measured in some cases
- For instance, studies of the 1/100 annual exceedance flood usually come with uncertainty bounds
- Another place is the PSHA, one to two standard deviation plots

Uncertainty/Confidence

- However, uncertainty can accumulate in risk analyses
- Final risk numbers rarely come with precise uncertainty bounds
- Monte Carlo Analysis is often used to help define the limits of confidence in an estimate

Uncertainty/Confidence

from Reclamation Best Practices



Concept of Best Estimate

- Most FERC analyses will have been done with conservative estimates, particularly dambreak studies.
- Quantitative risk analyses requires using best estimates (sometimes mean estimates)
- Examples of best estimate development will be discussed tomorrow.

DISCUSSION/QUESTIONS?