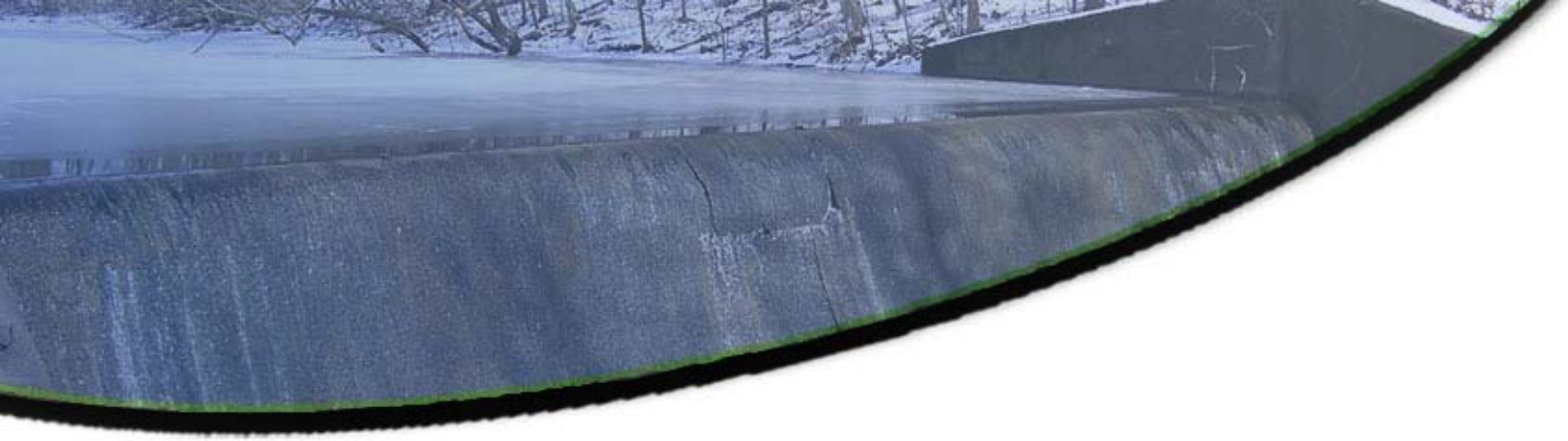


Benefits of Risk Analysis

Guy S. Lund, PE
URS Corporation

Risk Analysis – Goals

- Understand failure mechanisms related to dam safety
- Understand potential impacts (economic, social, life, other)
- Allocation of funds that will contribute the greatest toward risk reduction

Risk Analysis – Definitions

- **Risk**
  - Product of **PROBABILITY OF FAILURE** times **CONSEQUENCE**
- **Failure probability**
  - Quantitative estimate of potential failure
- **Consequence**
  - Losses due to dam failure scenario
- **Failure Mode**
  - Description that states the steps (process) that leads to uncontrolled release of the reservoir

Risk Analysis

- Levels the playing field
  - Typical loads: Usual, Unusual, Extreme
    - *Usual – normal, every day load*
    - *Unusual – PMF range from 10,000 to 100,000 yr. event*
    - *Extreme – MCE usually defined as 10,000 yr event*

Risk Analysis

- Levels the playing field
  - Typical loads: Usual, Unusual, Extreme
    - *Usual – normal, every day load*
    - *Unusual – PMF equates to 100,000 yr. event*
    - *Extreme – MCE equates to 10,000 yr event*
  - Risk takes into account the likelihood of the event
    - *Likelihood of Usual Load = 100 %, or 1.0*
    - *Likelihood of PMF = 1/100,000 or 10^{-5}*
    - *Likelihood of MCE = 1/10,000 or 10^{-4}*

Risk Analysis

- Levels the playing field
- Prioritization (allocation of available resources)

Project #1

Project #2

Project #3

Project #4

?

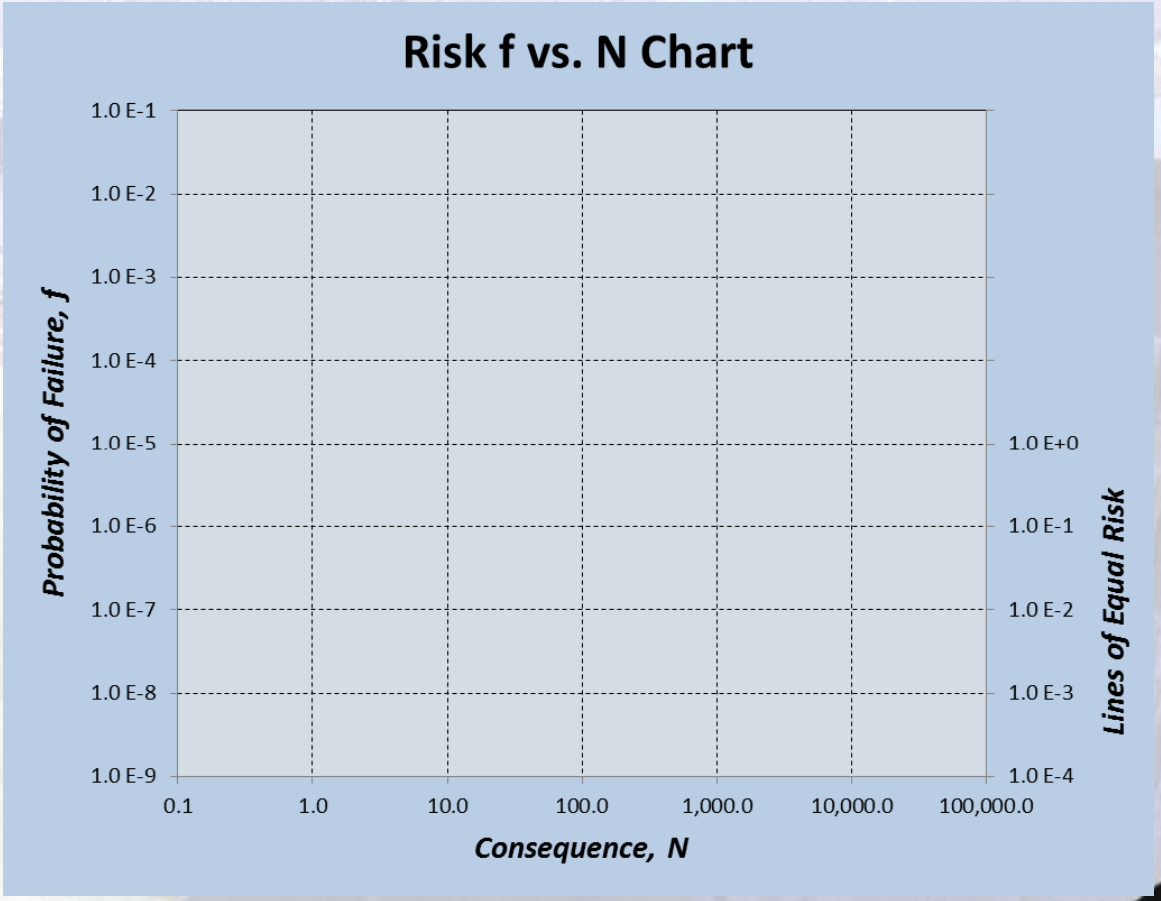
Risk Analysis

- Levels the playing field
- Prioritization (decision-making)
- Highlights topics we always knew, but didn't discuss
  - Consequences cannot be eliminated
  - Probability of failure cannot be eliminated
  - Importance of Surveillance and Monitoring
  - UNCERTAINTIES

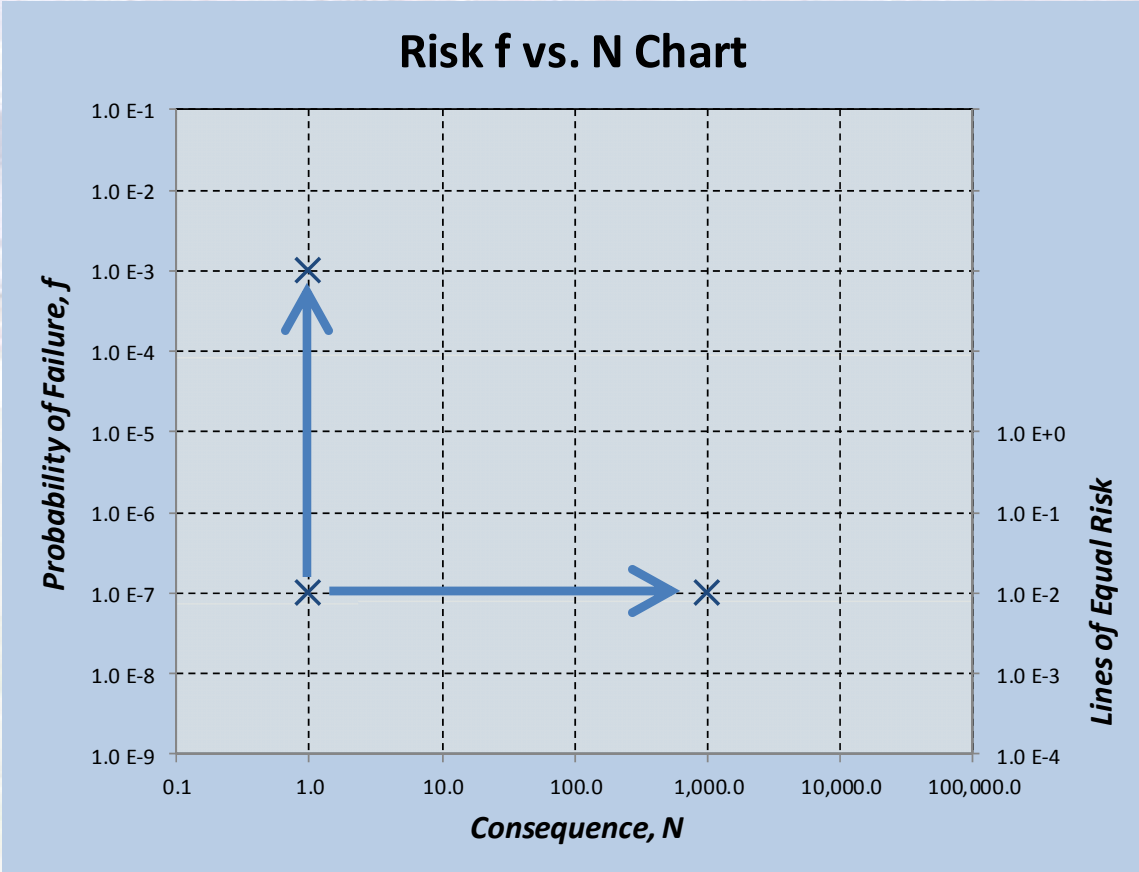
Risk Analysis

- Replacement to traditional dam safety
- Design criteria

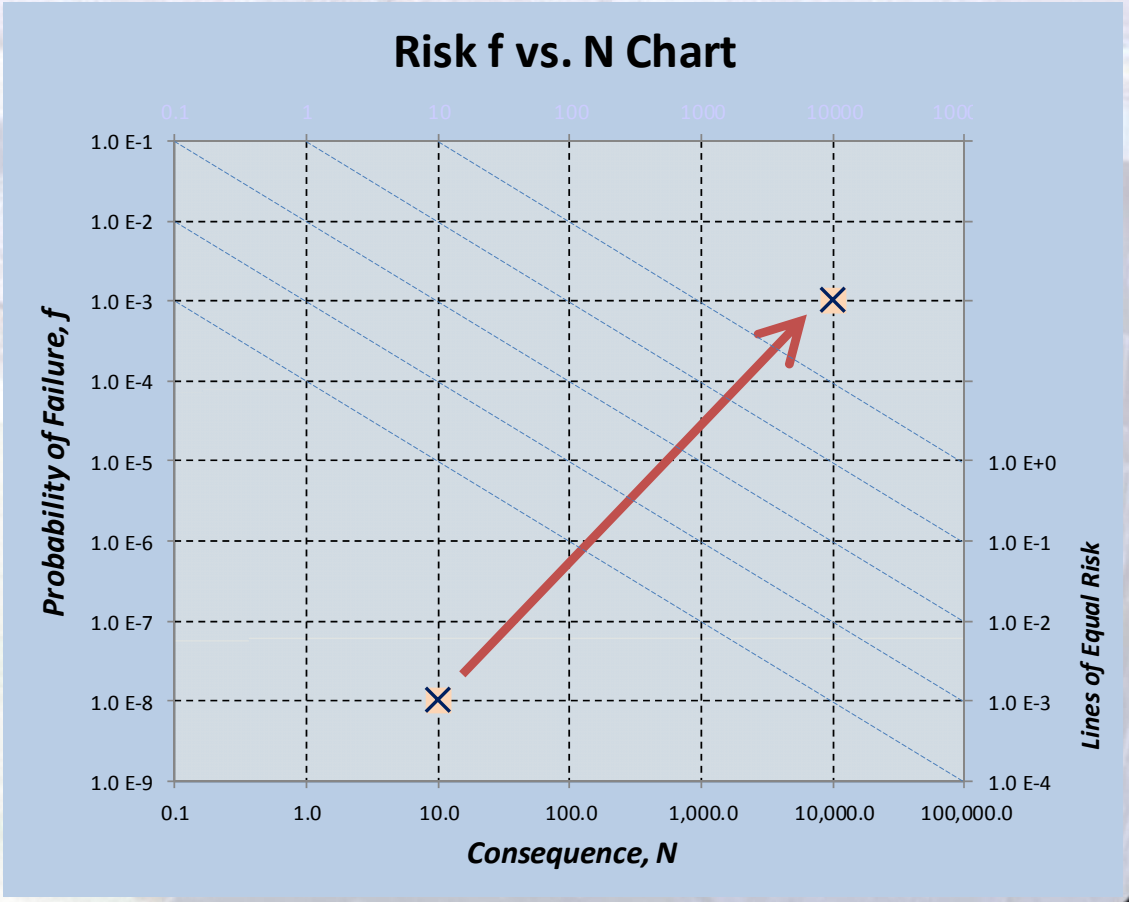
Risk Analysis – Evaluating Results



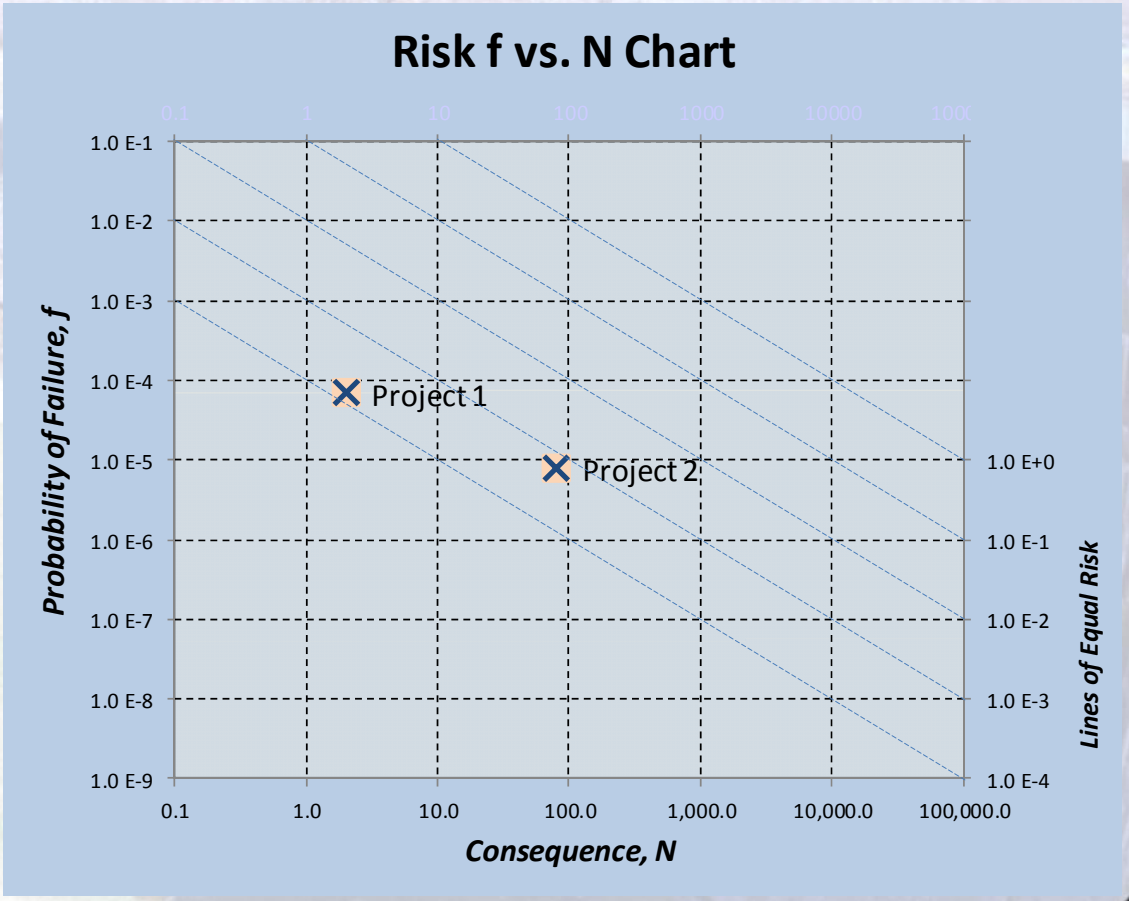
Risk Analysis – Evaluating Results



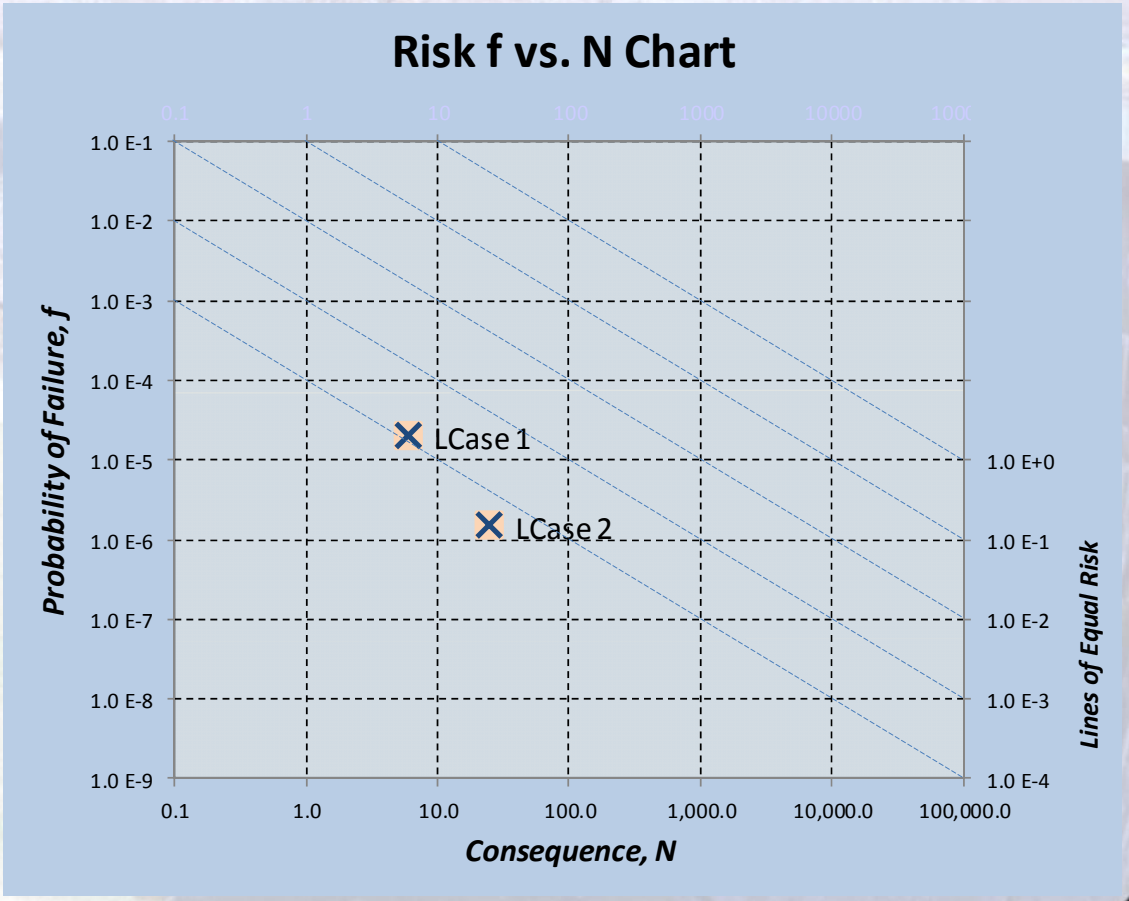
Risk Analysis – Evaluating Results



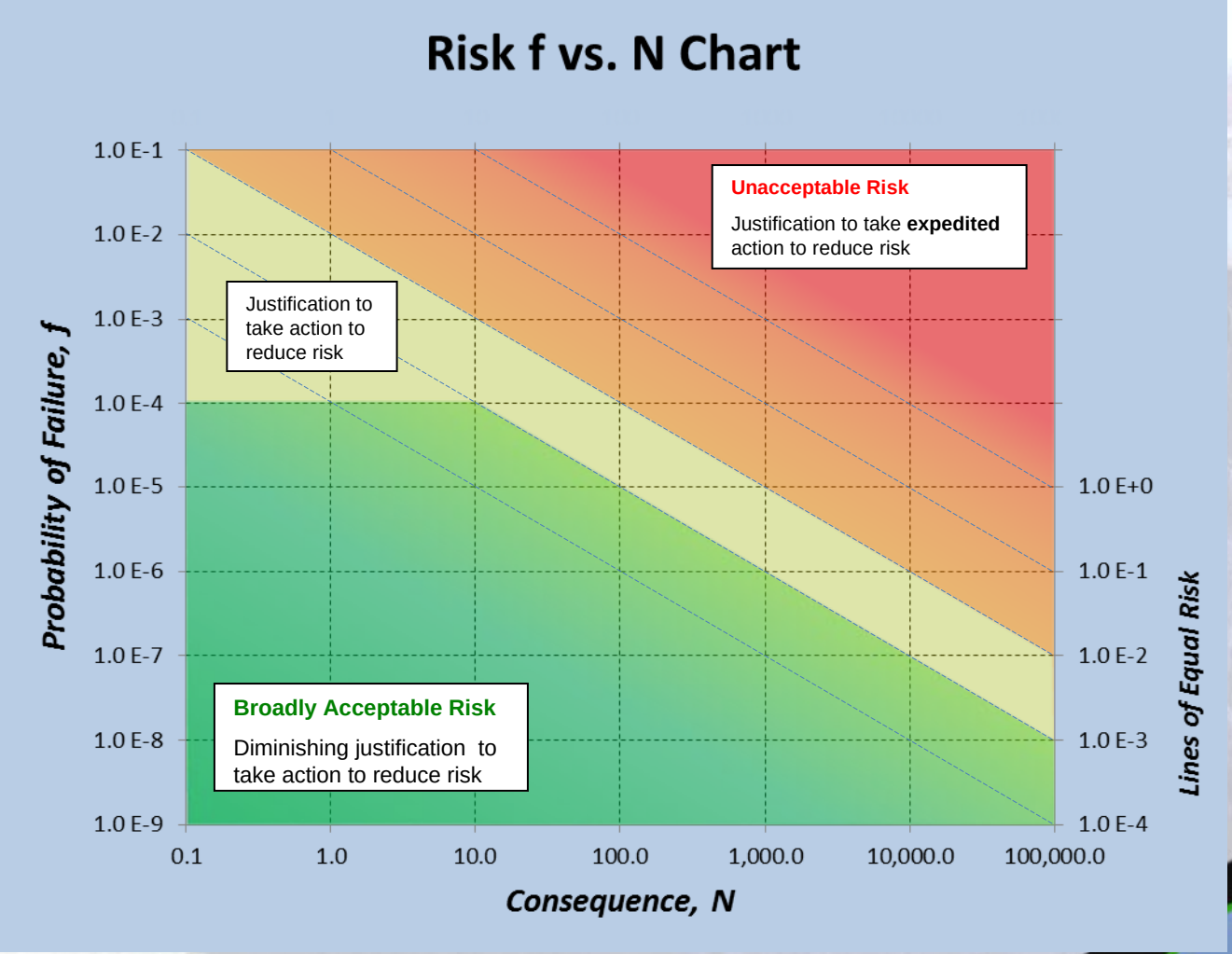
Risk Analysis – Evaluating Results



Risk Analysis – Evaluating Results

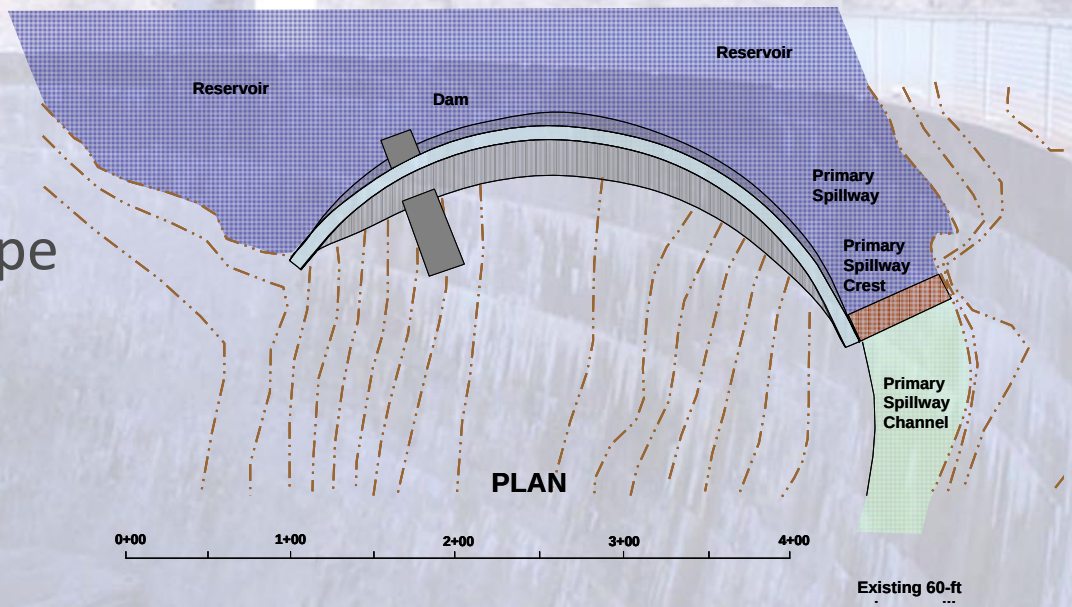


Risk Analysis – Evaluating Results



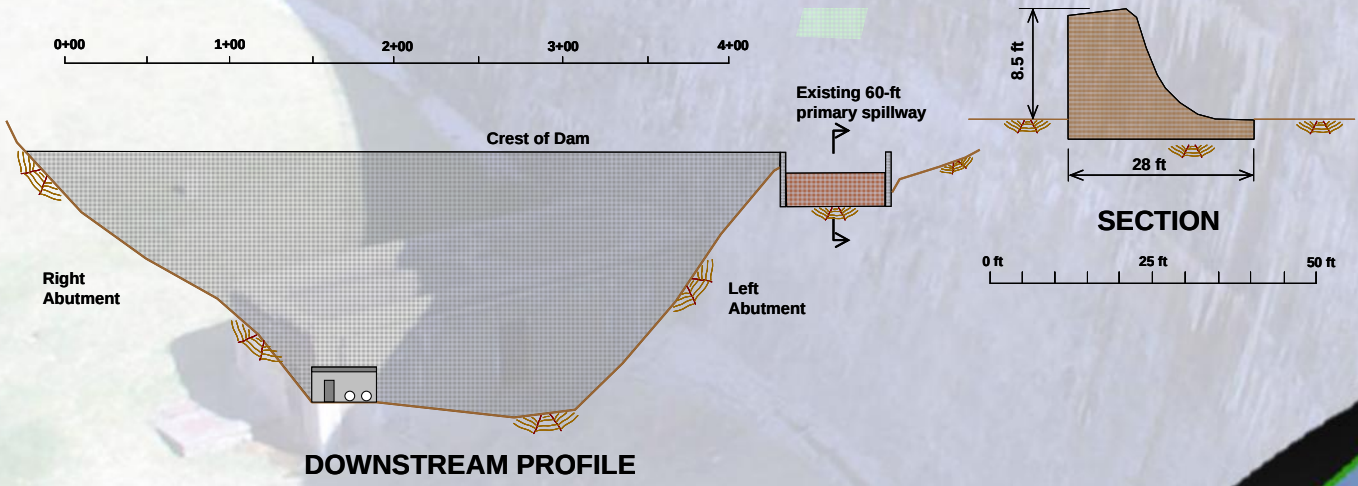
Concrete Dam – Case Study

- Single curvature arch
  - Height: 75 feet
  - Crest: 450 feet
  - Uncontrolled Ogee-type Spillway
    - *Width 60 feet*
- HIGH Hazard



Concrete Dam – Case Study

- Safety Evaluation
  - Foundation rock consists of a fractured, horizontally layered sandstone and shale. Susceptible to erosion.
  - Spillway capacity inadequate to pass the inflow design flood. Overtop dam crest by 3.6 feet.
  - Spillway weir does not have adequate stability



Concrete Dam – Case Study

- Recommended Alternative
  - Spillway
    - *Increase spillway capacity but widening/lowering crest*
    - *Construct auxiliary spillway for additional discharge capacity*
  - Overtopping
    - *Construct parapet along dam crest to prevent overtopping*
  - Rock Scour
    - *Construct concrete apron to foundation prevent scour*

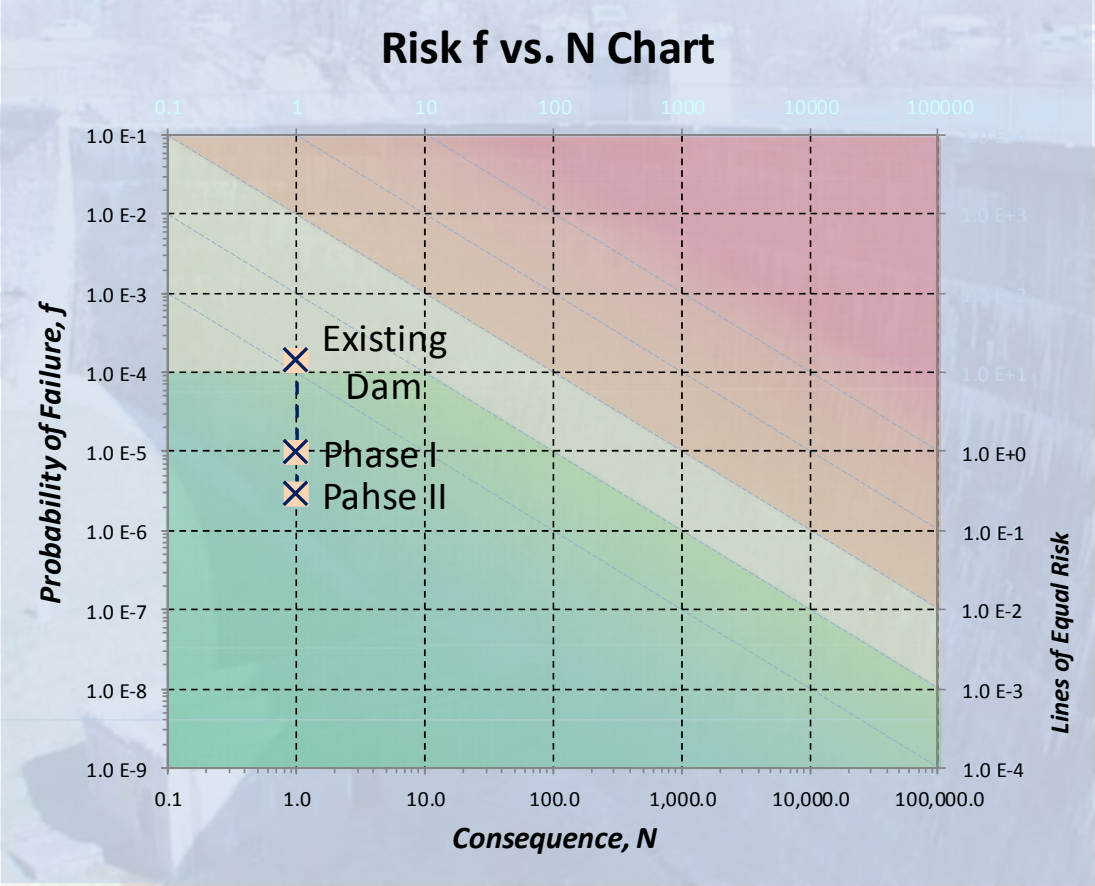
Concrete Dam – Case Study

- Recommended Alternative
- Estimated Cost
  - Greater than allocated funds
  - Full funding could impact ability to operate and maintain other dam projects

Alternatives

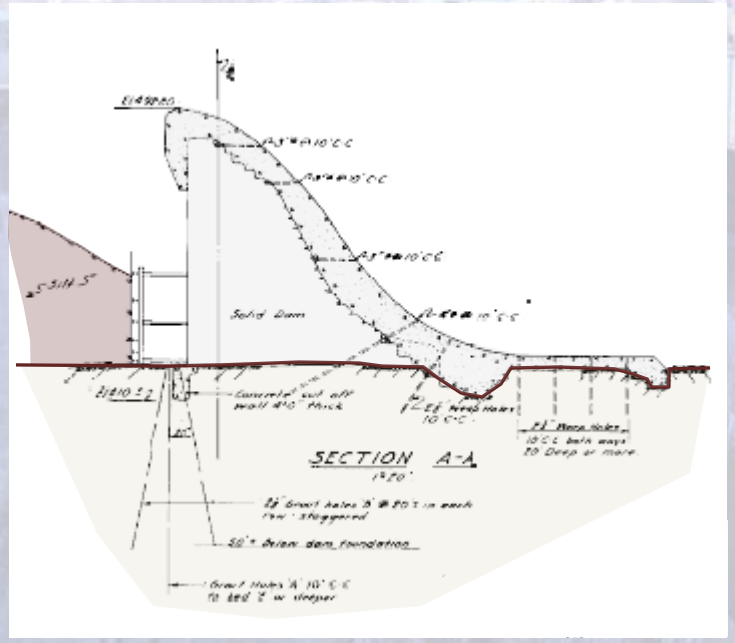
- Alternative No. 2
  - Existing Dam
  - Phase I - Demolition and removal of the existing spillway weir
  - Phase II - Saw cut and remove notch at center of arch dam.

Risk Analysis – Evaluating Results

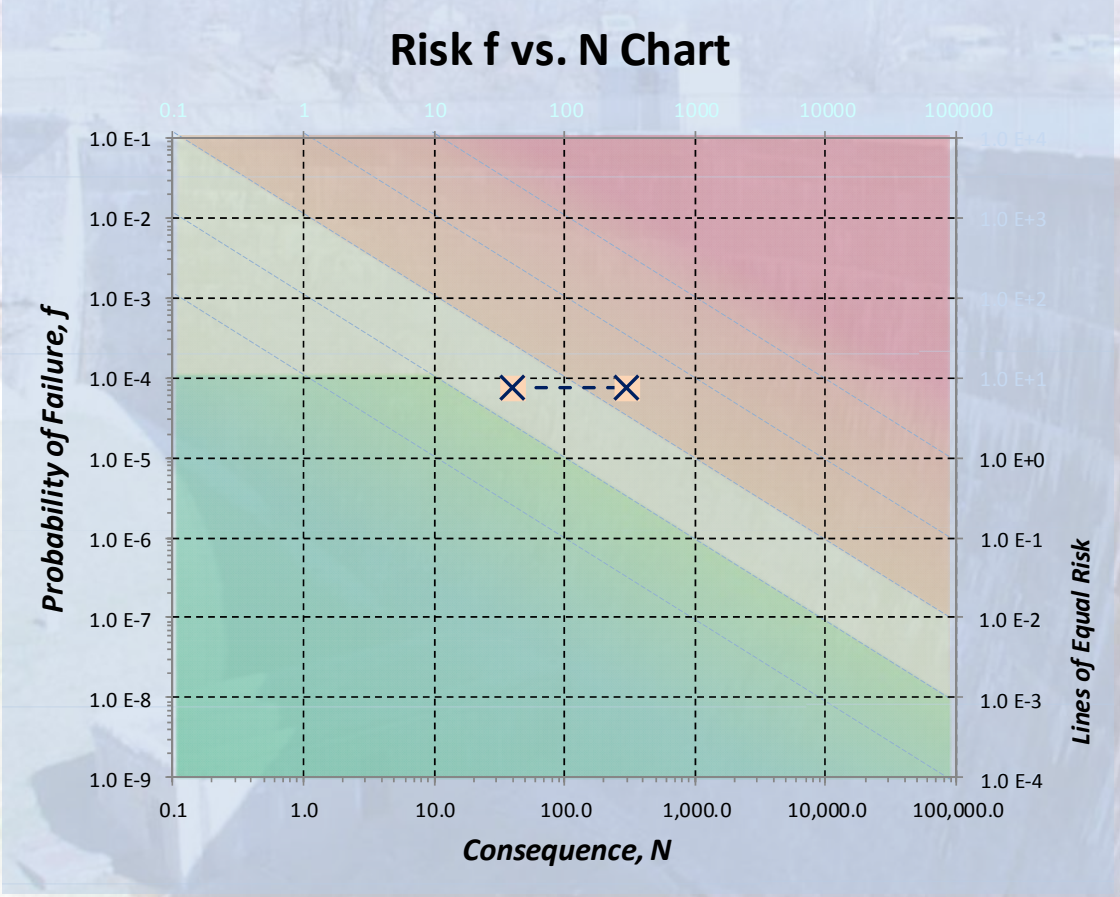


Concrete Dam – Case Study

- Composite Dam
  - Spillway Section
    - *Height:* *70 feet*
    - *Crest Length:* *450 feet*
  - Historical Record includes failure
  - Post-Tensioned Anchors
- HIGH Hazard
- Risk still greater than desired



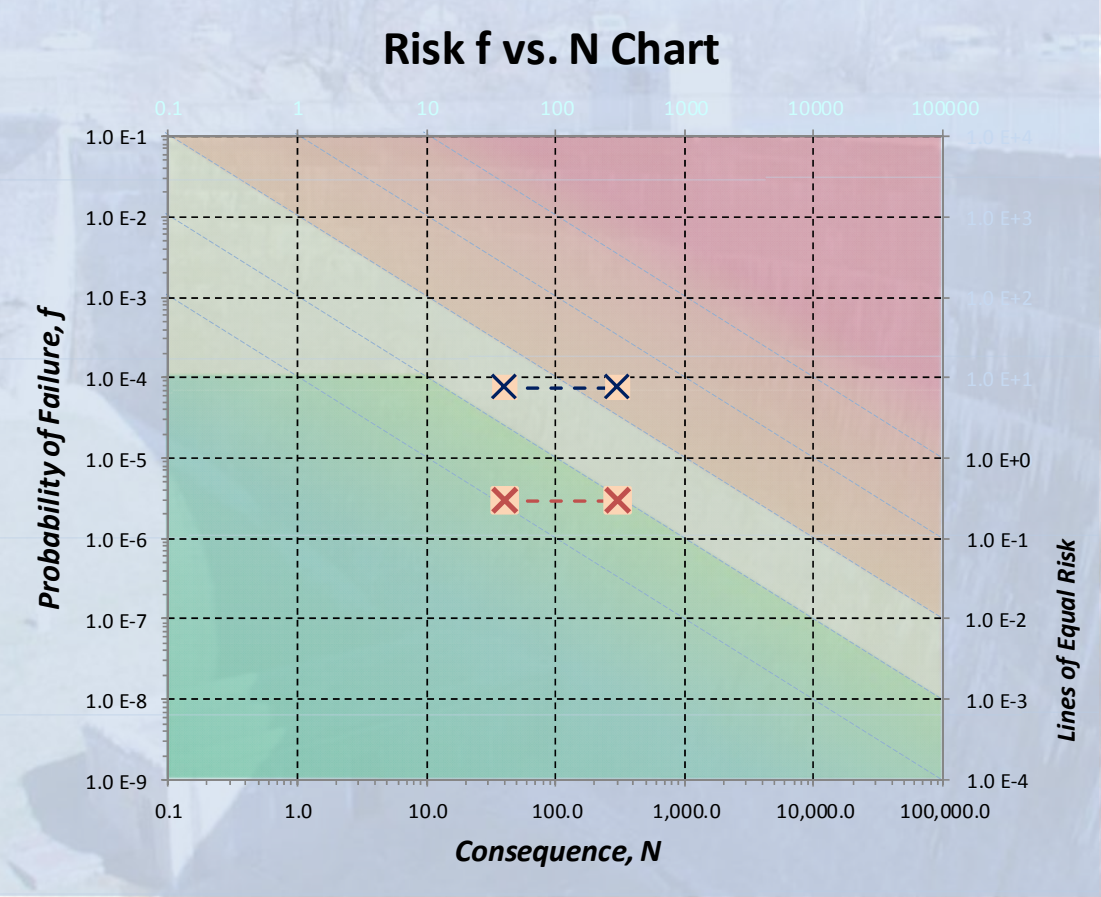
Risk Analysis – Evaluating Results



Potential Failure Mode

- Uplift Pressures Increase
  - The current system did not maintain the foundation drains, which can help reduce potential uplift pressures
  - Piezometers were inoperable, and can detect increase in uplift
  - If an increase in uplift is detected, then reservoir can be evacuated
- Effective Weight of Structure Reduces to Critical Level
  - If the uplift pressure increases it reduces the effective weight of the structure.
- Sliding Failure
  - The frictional resistance is less than driving force, and sliding failure occurs.

Risk Analysis – Evaluating Results



Lessons

- Importance of consistency
  - Risk analysis is typically performed in “team” setting after the engineering studies are complete.
- Risk is not eliminated
- Probability is not eliminated
- Risk is not a safety criteria
  - Prioritization tool
  - ALARP, as low as reasonably practicable
- Risk is not a design standard
  - Help determine critical load.
  - Design with acceptable codes

Questions