Dams Safety Program

SAME Industry Day
@UMKC
January 28, 2009

Douglas Crum, PE
1993 Flood
1997 & 2001 Floods
1997 & 2001 Floods
Katrina

Figure 5. Hurricane Katrina path and intensity history
Contents

1. Historic Dam Failures
2. Dam Safety Program Essential Tasks
3. Corps Priorities
4. Risk & Reliability
   a) Portfolio Risk Assessment (SPRA)
   b) Probable Failure Modes Analysis (PFMA)
5. Risk Management
South Fork Dam, PA (1880’s)

A schematic of the design for the Johnstown, Pa. South Fork Dam, circa 1840.
Ashley Dam, MA 1909
Sheffield Dam, CA (1925)

After the Santa Barbara Earthquake, June 29, 1925, Magnitude 6.2
St. Francis Dam, CA (1928)

SAN FRANCISQUITO CANYON, CA
Dedicated May 1926

2030 12 March 1928 12”
scarp in highway
2357 12 March 1928
massive abutment slide
0109 13 March 1928
Reservoir essentially empty
of Engineers

St. Francis Dam

Open cracks in Sespe Frm. that extend into Pelona Schist

Sespe Formation

Pelona Schist

San Francisquito Fault Plane
Fontenelle Dam, WY (1965)
San Fernando, CA (1971)

After the San Fernando Earthquake, Feb. 9, 1971, Magnitude 6.5
Teton Dam, Idaho (1976)
Swift #1, OR
Big Bay, Mississippi (2004)
Taum Sauk, Missouri (2005)
Failure Rates for Dams

Order of Magnitude Estimate: One dam failure for every 10,000 years of operation:

1. No. of Corps Dams = 610
2. Average Age = 55+ Years
3. No. of Dams Corps Dams that should have failed:
   \[ = 55 \times \frac{610}{10,000} \]
   \[ = 3.3 \]
DAM FAILURE CATEGORIES

• OVERTOPPING OR SPILLWAY INADEQUACY
• PIPING OR SEEPAGE
• MISCELLANEOUS

• About equal frequency
• Baecher, et. Al., Journal of Geotechnical Engineering, ASCE, January 1980
DAM FAILURE CATEGORIES

FUNCTIONALITY

- Overtopping: 30.3%
- Liquefaction: 3%
- Piping: 24.1%
- Failure of appurtenant structures: 1.9%

STABILITY

- Strength exceeded: 5.6%
- Water action: 11.7%
- Excessive deformation: 11.7%
- Strength diminishing: 11.7%

DURABILITY
## DAM FAILURE CATEGORIES

- **Causes Of Failure (Dams > 50’ High)** *

<table>
<thead>
<tr>
<th>Failure Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seepage &amp; Piping</td>
<td>62%</td>
</tr>
<tr>
<td>Overtopping</td>
<td>23%</td>
</tr>
<tr>
<td>Downstream Slope Failure</td>
<td>7%</td>
</tr>
<tr>
<td>Deformation</td>
<td>4%</td>
</tr>
<tr>
<td>Deterioration</td>
<td>4%</td>
</tr>
<tr>
<td>Gate Failure</td>
<td>1%</td>
</tr>
</tbody>
</table>

* Based On ASCE/USCOLD Study of 77 Failures
2. Dam Safety Program Essential Tasks
FEDERAL GUIDELINES FOR DAM SAFETY

• Prepared by the Ad Hoc Interagency Committee on Dam Safety, June 1979
• Reprinted April 2004  (FEMA 93)
• “…initiated by Pres. Carter in April 1977, to review procedures and criteria used by Federal Agencies involved in the design, construction, operation, and regulation of dams…”
ROUTINE DAM SAFETY PROGRAM

• Monitoring and Evaluation
  – Instrument & Survey Data Collection
  – Data Review and Analysis
  – Instrument Maintenance and Calibration
• Inspections
  – Informal Inspections at request of project staff
  – Annual
  – Periodic Inspections
  – Special Inspections for Events (e.g. Emergency Response, Record Pool, Seismic Event)
  – Special Inspections for Project Features (e.g. Hydraulic Steel Structures, Reservoir Rim, Dewatering Inspections)
ROUTINE DAM SAFETY PROGRAM

- Emergency Preparedness
  - EAP Updates
  - Dam Safety Training for the Operating project personnel
  - Emergency Exercises
- As Needed
  - Maintenance that assures safe operations of a dam (Relief Wells, Foundation Drains, Dewatering Locks and Stilling Basins, Vegetation Control, Lubrication of Mechanical Equipment, Cathodic Protection)
  - Dam Safety Issue Resolution Support to Project Personnel
  - Supplemental Design / Analysis/ Evaluations During the Project Life Cycle (Seismic Reviews, Hydrologic capacity, Seepage or stability concerns)
3. Corps Priorities

- CENTER HILL DAM, TN
- CLEARWATER DAM, MO
- HERBERT HOOVER DIKE, FL
- ISABELLA DAM, CA
- MARTIS CREEK DAM, CA
- MILL CREEK DAM, WA
- WOLF CREEK, KY
- ZOAR LEVEE (DOVER DAM), OH
• Largest reservoir east of the Mississippi River, and the ninth largest in the United States.
Clearwater Dam

Top of dam elevation 608
Top of parapet wall 611
Pool elevation 494
POOL OF RECORD – MAY 2002
LOOKING TOWARDS LEFT ABUTMENT
Clearwater Dam – Sinkhole Investigation
15 January 2003
Original Construction – STA 41+68

Looking E from 150' U.S. of station 41+68: General view of cut-off trench operations.
Looking S from 175' US of station 39 / 20: Open joint in cut-off trench foundation.
4. Risk & Reliability
Screening-level Portfolio Risk Assessment (SPRA)

- FY05: Tuttle Creek & Harlan County
- FY06: Truman & Kanopolis
- FY07: Milford & Perry
- FY08: Blue Springs, Clinton, Pomme de Terre, & Stockton
- FY09: Hillsdale, Long Branch, Longview, Melvern, Pomona, Rathbun, Smithville, & Wilson
SPRA Results FY05 - 07

Flood Damage Reduction Projects

95, 55%

6, 3%

36, 21%

37, 21%

DSAC 1  DSAC 2  DSAC 3  DSAC 4
SPRA Results FY05 – FY07
# DSAC Table (Simplified Characteristics)

<table>
<thead>
<tr>
<th>Dam Safety Action Class</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I Urgent &amp; Compelling (Unsafe)</strong></td>
<td>Critically Near Failure or Extremely High Risk: Failure expected under normal operations within a few years without intervention.</td>
</tr>
<tr>
<td><strong>II Urgent (Potentially Unsafe)</strong></td>
<td>Failure Initiation Foreseen or Very High Risk: Could initiate under normal operations or an event. Risk too high to assure public safety.</td>
</tr>
<tr>
<td><strong>III High Priority (Conditionally Unsafe)</strong></td>
<td>Significantly Inadequate or Moderate to High Risk: Confirmed or unconfirmed issues.</td>
</tr>
<tr>
<td><strong>IV Priority (Marginally Unsafe)</strong></td>
<td>Inadequate with Low Risk: Probability of failure is low, but may not meet all essential guidelines.</td>
</tr>
<tr>
<td><strong>V Normal (Safe)</strong></td>
<td>Adequately Safe: Residual risk is considered tolerable.</td>
</tr>
</tbody>
</table>
## DSAC Table (Simplified Actions)

<table>
<thead>
<tr>
<th>Dam Safety Action Class</th>
<th>IRRM</th>
<th>Heightened Monitoring &amp; Evaluation</th>
<th>Class Validation</th>
<th>Remediation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Urgent &amp; Compelling (Unsafe)</td>
<td>X</td>
<td>X</td>
<td>External Peer Review</td>
<td>Expedite Remediation, Situation Reports</td>
</tr>
<tr>
<td>II Urgent (Potentially Unsafe)</td>
<td>X</td>
<td>X</td>
<td>Expedite Studies</td>
<td>Priority for Remediation</td>
</tr>
<tr>
<td>III High Priority (Conditionally Unsafe)</td>
<td>X</td>
<td>X</td>
<td>Priority for Studies</td>
<td>Normal Priority for Remediation</td>
</tr>
<tr>
<td>IV Priority (Marginally Unsafe)</td>
<td></td>
<td>X</td>
<td>Normal Priority for Studies</td>
<td>Normal Priority for Remediation</td>
</tr>
<tr>
<td>V Normal (Safe)</td>
<td></td>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Reliability Applications

1. Economic/Feasibility Studies (B/C ratios)
2. Design Methodology (LRFD)
3. Prioritizing Programs
4. Communicating Issues to Public (Katrina)
5. Engineering Decisions (Duncan, ASCE)
Risk Application Categories

- **PFMA – Probable Failure Modes Analysis**
  - Failure Modes Identification
  - Qualitative diagnostic approach, not a decision tool

- **SPRA – Screening Level Portfolio Risk Assessment**
  - Index based prioritization

- **PRA - Portfolio Risk Assessment**
  - Quantitative risk based prioritization

- **Quantitative Risk Assessment**
  - Risk analysis, assessment, and recommendations toward risk management
4a. Portfolio Risk Assessment (SPRA)

- Screening-Level (SPRA)
- Refining the Risk Estimates (PRA)
Risk Components

\[ Risk = \Phi\{P_f, C, ConfidenceLevel\} \]

\[ Risk = [P(A) \times P(f_c \mid A) \times P(f_d \mid f_c)] \times C \]

C – Consequences (Usually LOL or $, can be HU, etc.)

P(A) – Probability of Annual Loading

P(f_c) – Probability of failure for a component

P(f_d) – Probability of dam failure
Event Tree

Annual Loading

50-yr Pool

P(A)=.01

100-yr Pool

P(f_c)=.01 (FS<1)

1-P(f_c)=.99 (FS>1)

500-yr Pool

50-yr Pool

P(f_c)=.01 (FS<1)

P(FC)=.01

1-P(FC)=.99 (FS>1)

Probabilities sum to 1

Performance Level

Consequences

Catastrophic

P=.05

Dam Failure

C=$500M

R=$2500

Emergency

C=$5M

R=$75

Low Impact

P=.80

Routine

C=$50K

R=$36

Probabilities sum to 1

Catastrophic

P=.05

Low Impact

P=.80

Probabilities sum to 1

Catastrophic

C=$500M

R=$2500

Low Impact

C=$50K

R=$36

Probabilities sum to 1
SPRA Index Rating Definitions

- **Adequate (A)** - Supported by data, studies, or project characteristics. Meets current engineering standards.
- **Probably Adequate (PA)** - Performance shows low level of confidence and may not meet criteria. Additional investigations to confirm adequacy.
- **Probably Inadequate (PI)** – Performance shows low level of confidence and does not meet criteria. Additional investigations to confirm inadequacy.
- **Inadequate (I)** – Distress is present. Factor of safety near limit state.
Economic Analysis

Probable Failure Point (PFP)

Probable Non-failure Point (PNP)

Probability of failure if water surface reaches stage shown
Reliability Criteria

• PGL No. 26 (1991)
  • Requires reliability approach for levees
  • Mentions PFP/PNP

• ETL 1110-2-328 (1993)
  • Template Method, rescinded 1998

• ER 1105-2-101 (1996)
  • Requires risk analysis for flood damage reduction studies

• EM 1110-2-1619 (1996)
  • Economics

• ETL 1110-2-556 (1999)
  • Geotechnical risk analysis for planning studies
  • Appendix B, “Evaluating the Reliability of Existing Levees”
Probability of Failure

1. Empirical (Statistics)
2. Logic (Event trees, Fault Trees)
3. Judgment (Expert Elicitation)
4. Probabilistic Analysis of a Failure Mechanism
Probabilistic Analysis of a Failure Mechanism

• Taylor’s Series
  • First Order – Second Moment Method (FOSM)
• Point Estimate
• Advanced Method (Hasofer & Lind)
• Monte Carlo

# Periodic Assessment Modules

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>New District Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cover</td>
<td></td>
<td>Currently in A Periodic Inspection</td>
</tr>
<tr>
<td>2.</td>
<td>Findings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Recommendations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Description of Dam and Operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Evaluation of Materials and Methods</td>
<td></td>
<td>New District Activity</td>
</tr>
<tr>
<td>6.</td>
<td>Performance Evaluation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Engineer’s Inspection Report (EIR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Static Hazard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Hydrologic Hazard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Seismic Hazard</td>
<td></td>
<td>New Risk Based Activities</td>
</tr>
<tr>
<td>11.</td>
<td>Potential Failure Modes Assessment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Consequences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Analysis of Risk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Performance Monitoring</td>
<td></td>
<td>New District Activity</td>
</tr>
</tbody>
</table>
Tool Box Modules

- Seepage and Piping Toolbox
- Hydrology & Hydraulic Toolbox
- Stability Toolbox
- Structural Stability Toolbox
- Erosion Toolbox
- Seismic Toolbox
- Mechanical Toolbox
- Human Factor Toolbox
- Consequence Toolbox (Economics, Loss of Life)
4b. Probable Failure Modes Analysis (PFMA)
## PFMA Purposes

<table>
<thead>
<tr>
<th>FERC</th>
<th>Corps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recover Institutional Knowledge</td>
<td></td>
</tr>
<tr>
<td>Identify most likely failure modes</td>
<td>Precursor to Quantitative Risk Analysis</td>
</tr>
<tr>
<td>Identify risk reduction opportunities</td>
<td>Interim Risk Reduction Measures</td>
</tr>
<tr>
<td>Focus instrumentation &amp; inspection</td>
<td>Performance Monitoring Plan</td>
</tr>
<tr>
<td>Avoid Operational Failures</td>
<td></td>
</tr>
</tbody>
</table>
PFMA Process

1. Team
   - Leader, Core Disciplines, Facilitator
2. Collection & Review of Data
3. Site Inspection of Project
4. PFMA Charrette Session
5. *Performance Monitoring Plan (FERC)*
6. PFMA Report
PFMA Categories

I  **Highlighted Potential Failure Mode**  
The physical possibility is reasonable and credible.

II  **Potential Failure Mode Considered but not Highlighted**  
Those of lesser significance and likelihood.

III  **More Information or Analyses are needed in order to Classify**  
Lacked information at the time of the PMFA.

IV  **Potential Failure Mode Ruled Out**  
Clearly so remote as to be non-credible or not reasonable to postulate.
PFMA Results

<table>
<thead>
<tr>
<th>No</th>
<th>Potential Failure Modes Description</th>
<th>Initiator - Sequence Of Events Leading To Failure</th>
<th>Adverse Conditions - Failure More Likely</th>
<th>Positive Conditions - Failure Less Likely</th>
<th>Consequences</th>
<th>Risk Reduction Measures</th>
<th>Cat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Foundation drain overload in the structure causing increased uplift in the foundation which leads to sliding failure of the structure</td>
<td>High pool levels could cause an upstream crack from movement of the foundation, increasing flow in the drains beyond their capacity.</td>
<td>High pool levels could overwhelm the drains. This would cause an increase in foundation pressures. Uplift is critical to the sliding stability.</td>
<td>Deformation during previous record pools has been minimal and if the drains are cleaned and maintained this failure is less likely to occur</td>
<td>Sliding of the spillway would result in loss of the reservoir, but bedrock is higher in the vicinity of the spillway and abutments may have some restriction of flows.</td>
<td>Maintain the foundation drains in the structure, monitor the piezometric levels to know when to clean drains.</td>
<td>3</td>
</tr>
</tbody>
</table>
5. Risk Management
Risk Strategies

• Communication: Situational awareness of the risks associated with dams and levees.
• Programs: Centrally prioritize studies, investigations, and rehabilitation projects.
• Interim Measures: Manage and reduce risk with cost-effective approaches.
• Engineering: Utilize risk based methods in engineering and design.
Organization

- **SOG** (Senior Oversight Group) - Primarily Headquarters (HQUSACE) and risk experts.

- **DSSC** (Dam Safety Steering Committee) - Division dam safety program managers and ad hoc District members.

- **Methodology Team** – Primarily the Engineering Risk and Reliability District of Expertise (ERRDX).

- **Risk P&P** (Policy and Procedures) - Senior technical experts throughout USACE. Work in tandem with the methodology team.

- **Risk Cadres** - Performing Screening for Portfolio Risk Analysis (SPRA) since 2005 and will be completing risk based modules for Periodic Assessments starting in 2010.

- **MSC** (Major Subordinate Command) – "Division Offices"
Reliability Criteria

- **ETL 1110-2-547 (1997)**
  - Probability and Reliability Methods for Geotechnical Engineering

- **ETL 1110-2-561 (2006)**
  - Reliability Analysis And Risk Assessment For Seepage And Slope Stability Failure Modes For Embankment Dams

- **EC 1110-2-6061(Revision - 2009 Draft)**
  - Safety of Dams – Policy and Procedures
Managing Uncertainty

Risk management trends toward the side of safety to ensure public protection.

Confidence in risk estimate increases as uncertainty decreases.
## Budget Prioritization

Table IV-5. Hydropower Risk Matrix

<table>
<thead>
<tr>
<th>Consequence Category</th>
<th>Condition Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F Failed</td>
</tr>
<tr>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
</tr>
</tbody>
</table>

- **Red** = Extreme Risk
- **Orange** = High Risk
- **Green** = Low Risk
## NWK Ranking Matrix

### Table - NWK DAM SAFETY RELATIVE RISK RANKING MATRIX

<table>
<thead>
<tr>
<th>Effects</th>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>Annual Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$/yr</td>
<td>$/yr</td>
<td>$/yr</td>
<td>$/yr</td>
<td>$/yr</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$500k</td>
<td>$50k</td>
<td>$50k</td>
<td>$50k</td>
<td>$50k</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5M</td>
<td>$5M</td>
<td>$5M</td>
<td>$5M</td>
<td>$5M</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$500M</td>
<td>$500M</td>
<td>$500M</td>
<td>$500M</td>
<td>$500M</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5x10^{-4}/yr</td>
<td>$5x10^{-4}/yr</td>
<td>$5x10^{-4}/yr</td>
<td>$5x10^{-4}/yr</td>
<td>$5x10^{-4}/yr</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5k</td>
<td>$5k</td>
<td>$5k</td>
<td>$5k</td>
<td>$5k</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$100M</td>
<td>$100M</td>
<td>$100M</td>
<td>$100M</td>
<td>$100M</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5 - 10</td>
<td>$5 - 10</td>
<td>$5 - 10</td>
<td>$5 - 10</td>
<td>$5 - 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Environmental - Extensive mitigation</td>
<td>Environmental - Extensive mitigation</td>
<td>Environmental - Extensive mitigation</td>
<td>Environmental - Extensive mitigation</td>
<td>Environmental - Extensive mitigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Some Warning of failure</td>
<td>Loss of Life &gt; 1</td>
<td>Economic Loss = $10M - $100M</td>
<td>B/C ratio = 5 - 10</td>
<td>Lifeline – Some disruption of critical facilities or infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adequate Warning of failure</td>
<td>Loss of Life = 0, but some PAR</td>
<td>Economic Loss = $1M - $10M</td>
<td>B/C ratio = 2 - 5</td>
<td>Lifeline – Minor disruption of critical facilities or infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adequate Warning of failure</td>
<td>Loss of Life = 0, Minimal to no PAR</td>
<td>Economic Loss &lt; $100k</td>
<td>B/C ratio &lt; 2</td>
<td>Lifeline – No disruption of critical facilities or infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Environmental - Major mitigation</td>
<td>Environmental – Some mitigation</td>
<td>Environmental – Some mitigation</td>
<td>Environmental – Some mitigation</td>
<td>Environmental - Minor damage</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Warning of failure</td>
<td>Loss of Life &amp; PAR is high</td>
<td>Economic Loss &gt; $100M</td>
<td>B/C ratio &gt; 10</td>
<td>Lifeline – Disruption of critical facilities or infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$500k</td>
<td>$50k</td>
<td>$50k</td>
<td>$50k</td>
<td>$50k</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5M</td>
<td>$5M</td>
<td>$5M</td>
<td>$5M</td>
<td>$5M</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$500M</td>
<td>$500M</td>
<td>$500M</td>
<td>$500M</td>
<td>$500M</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5x10^{-4}/yr</td>
<td>$5x10^{-4}/yr</td>
<td>$5x10^{-4}/yr</td>
<td>$5x10^{-4}/yr</td>
<td>$5x10^{-4}/yr</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5k</td>
<td>$5k</td>
<td>$5k</td>
<td>$5k</td>
<td>$5k</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$100M</td>
<td>$100M</td>
<td>$100M</td>
<td>$100M</td>
<td>$100M</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$5 - 10</td>
<td>$5 - 10</td>
<td>$5 - 10</td>
<td>$5 - 10</td>
<td>$5 - 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Environmental - Extensive mitigation</td>
<td>Environmental - Extensive mitigation</td>
<td>Environmental - Extensive mitigation</td>
<td>Environmental - Extensive mitigation</td>
<td>Environmental - Extensive mitigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Some Warning of failure</td>
<td>Loss of Life &gt; 1</td>
<td>Economic Loss = $10M - $100M</td>
<td>B/C ratio = 5 - 10</td>
<td>Lifeline – Some disruption of critical facilities or infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adequate Warning of failure</td>
<td>Loss of Life = 0, but some PAR</td>
<td>Economic Loss = $1M - $10M</td>
<td>B/C ratio = 2 - 5</td>
<td>Lifeline – Minor disruption of critical facilities or infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adequate Warning of failure</td>
<td>Loss of Life = 0, Minimal to no PAR</td>
<td>Economic Loss &lt; $100k</td>
<td>B/C ratio &lt; 2</td>
<td>Lifeline – No disruption of critical facilities or infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Environmental - Major mitigation</td>
<td>Environmental – Some mitigation</td>
<td>Environmental – Some mitigation</td>
<td>Environmental – Some mitigation</td>
<td>Environmental - Minor damage</td>
<td></td>
</tr>
</tbody>
</table>

### Notes
- **Failure Forecasted Loss of Service**
- **Inadequate Design Issue & Signs of Distress**
- **Probably Inadequate Design or Performance Issue**
- **Probably Adequate Design or Performance Questionable**
- **Adequate Routine Maintenance Need**
Conclusions

- Dam failures continue to occur on a regular basis. The possibility of a large federal dam breaching cannot be completely eliminated.
- Corps, Reclamation & FERC are aggressively proceeding with reliability analysis and risk assessments.
- Goal is to communicate with congress and stakeholders for risk informed decisions on maintenance and rehabilitation of dams.