Qualitative Risk Analysis

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

What is Risk?

- "Risk is a function of three terms: ν_{LL} (frequency of life loss), LL (actual number of lives lost), and p (probability that provides a measure of the uncertainty in the analysis) *Martin McCann, Stanford University*

Risk

Risk = Probability of Failure x Consequences

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

FERC Challenges

- Compared to other Federal agencies using risk, FERC inventory is much larger

    - Off the shelf tools not available (or must be modified)

- Staff, consultants, and licensees not familiar with risk approaches or methodologies

- Large inventory + Staff inexperienced using risk + Limited resources = Investment/Commitment Needed

FERC Challenges

- Current PFMs are not universally well described
- Some PFMAs did not consider all pertinent PFMs
- No existing FFA information readily available
- No existing PSHA information readily available
- No to very limited consequence information (PAR, PLL) information available

Step 1: Potential Failure Mode Analysis (PFMA)

Table 1 - Categories of Identified Potential Failure Modes

Category I - Highlighted Potential Failure Modes - Those potential failure modes of greatest significance considering need for awareness, **potential for occurrence, magnitude of consequence and likelihood of adverse response** (physical possibility is evident, fundamental flaw or weakness is identified and conditions and events leading to failure seemed reasonable and credible) are highlighted.

Category II - Potential Failure Modes Considered but not Highlighted - These are judged to be of **lesser significance and likelihood**.

Category III - More Information or Analyses are Needed in order to Classify
.
Category IV - Potential Failure Mode Ruled Out Potential failure modes may be ruled out because the physical possibility does not exist, information came to light which eliminated the concern that had generated the development of the potential failure mode, or the **potential failure mode is clearly so remote a possibility as to be non-credible or not reasonable to postulate.**

FERC Engineering Guidelines, Chapter 14

Step 2: Screening Level Portfolio Risk Analysis (SLPRA)

SLPRA

- The FERC has developed a SLPRA tool to begin the process of screening risk at all high and significant hazard dams in our inventory.

- All Regional Offices have been trained in the tool. All high and significant hazard dams will be completed by the end of September 2012.

- This information will be used to help in the prioritization of our inventory for use in selecting projects for risk analysis and in prioritizing resources.

- The SLPRA tool is a simplistic form of QRA.

Step 3: Qualitative Risk Analysis (QRA)

QRA

❑   Qualitative Risk Analysis is the next level above a screening level tool to evaluate risk.

❑   The Corps of Engineers has decided to conduct Periodic Assessments of their dams every 10 years using QRA.

❑   QRA uses more complete information than the FERC SLPRA tool.

QRA

- Next logical step in PFMA process
  - Taking PFM's and categories to a deeper understanding
    - Not all Category I and II PFM's are equivalent
      - Is a Cat II piping failure mode driven by past observance of sediment retained behind a seepage weir many years ago for a dam 15 miles upstream of one or two houses the same as
      - A Cat II overtopping failure mode due to PMF flows failing a dam with a small town located immediately downstream of the dam the same as
      - A Cat II overtopping failure mode due to inoperability of the dam's only spillway gate during a 100-year flood for a dam with a large population center located a short distance downstream of the dam?

QRA

- Next logical step in PFMA process Taking PFM's and categories to a deeper understanding
  - Ability to estimate potential consequences to public safety resulting from dam failure
  - Ability to more closely compare probability of failure between various potential failure modes
  - Ability to identify need for additional information, instrumentation and monitoring, inspection frequency, EAP testing requirements
  - Ability to more consistently define urgency of response and action
  - Others

FERC QRA Approach

- Three Phases
  - PFMA w/3 Qualitative Categories (I, II, and IV)
  - Screening Level Portfolio RA (Qualitative to Semi-Quantitative)
    - Simple potential life loss estimates
    - Flood and seismic failure modes loading estimated
    - Estimates within about 2 orders of magnitude for Annualized probability of failure APF
  - Team-Based QRA (Semi-Quantitative)
    - Slightly to significantly more refined loads (PSHA and FFA)
    - Better potential life loss estimates
    - Simple event trees for critical failure modes
    - Estimates within about 1 order of magnitude for APF?

QRA

- To complete a qualitative risk estimate, the following things are required.

  - At estimate of the likelihood of failure, which is the likelihood the loading times the likelihood of the dam failing from this loading.

  - Next, an estimate of the potential life loss consequences is needed.

  - The annualized likelihood of failure is charted on one axis and the potential life loss on another axis.

How to complete a QRA

- Review existing PFMs
  - Descriptions must be complete
  - PFMs must be comprehensive
- Review favorable and adverse factors
- Develop PFMs as fully as possible.

How to complete a QRA

- Select critical PFMs.

- Develop critical PFMs into event trees as follows.

  - Initiator: For instance, deterioration of a metal drain leads to beginning of backward internal erosion.

  - Step-by-step: Each step of developing a pipe to connect to the reservoir is developed.

  - Breach: Dam failure develops.

Probability of Load

- Probability of Load
    - Static Loading = Reservoir Elevation Frequency Curve
    - Flood Loading = Simple Flood Frequency Analysis (FFA)
    - Earthquake Loading = Probabilistic Seismic Hazard Analysis (PSHA), if available, or USGS Web information

How to complete a QRA - Probabilistic Loading

- Develop Probabilistic Seismic Hazard curves, as follows.

  - For dams in relatively aseismic regions, simply using the USGS probabilistic estimates might suffice.

  - For dams in seismic regions a full Probabilistic Seismic Hazard Analysis (PSHA) might be needed. These techniques are well known in seismic regions.

How to complete a QRA – Probabilistic Loading

- Develop Flood Frequency curves, as follows.
  - For dams with little likelihood of an overtopping failure or far from the warm oceans, simple extrapolations of 1/100 and 1/500 events.
  - Other dams may need a full flood frequency analysis (FFA).
  - However, the level of FFA should be commensurate with the detail needed. That is, only relative likely failure modes with large consequences may need a full blown FFA. Most likely these PFMs would eventually require a fully quantitative Probabilistic Risk Analysis anyway.

SLPRA Likelihood Categories

- The following tables were used for the SLPRA.

- The COE uses a similar but slightly different table for QRA

- For a FERC QRA these tables may change.

Likelihood of Failure

Category	General Description	APF
Remote	The physical conditions do not exist for its development or the likelihood is so remote. Several events must occur concurrently or in series to trigger failure. Most, if not all of the events are very unlikely. Or, it would likely take a flood or earthquake with a return period of more than 1,000,000 years to trigger the potential failure mode.	$< 10^{-6}$
Very Low	The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred or that a condition or flaw exists that could lead to its development. Or, a flood or earthquake with a return period of between 200,000 and 1,000,000 years would likely trigger the potential failure mode.	10^{-5}
Low	The fundamental condition or defect is known to exist, indirect evidence suggests it is plausible, but evidence is weighted more heavily toward unlikely than likely. Or, a flood or earthquake with a return period between 20,000 and 100,000 years would likely trigger the potential failure mode.	10^{-4}

Likelihood of Failure

Category	General Description	APF
Moderate	The fundamental condition or defect is known to exist, indirect evidence suggests it is plausible, but evidence is weighted more heavily toward likely than unlikely. Or, a flood or earthquake with a return period between 2,000 and 10,000 years would likely trigger the potential failure mode.	10^{-3}
High	There is direct evidence or substantial indirect evidence to suggest it has occurred or is likely to occur. Or, a flood or earthquake with a return period between 200 and 1,000 years would likely trigger the potential failure mode.	10^{-2}
Very High	There is direct evidence to indicate that it is actively occurring or is likely to occur. Or, a flood or earthquake with a return period of less than 100 years would likely trigger the potential failure mode.	$> 10^{-2}$

Likelihood Considerations

- The failure likelihood categories described above indicate the associated general range of annual probability of failure.

- Assign the failure likelihood category based on combination of likelihood of initiating loading and likelihood of dam failure from that loading.

- If the potential failure mode is initiated by a flood or seismic event, the probability of the load will greatly influence the appropriate failure likelihood category.

- For example, the failure likelihood category can be considered 'very low' or 'remote' for most PFMs initiated by floods near the PMF, if this extreme flood can be passed with reasonable flood routing assumptions.

Likelihood Considerations

- The failure likelihood category for static failure modes may prove to be more challenging.
  - Most risk methodologies for static failure modes are "calibrated" based on historical rates of failure mode initiation.
  - Many studies have been performed regarding the historical failure rates of dams, assessing various key parameters involved. In general, these studies tend to conclude that 1.0E-04 may be considered a rough dam failure/incident rate under static loading, with embankment dams slightly higher and concrete dams slightly lower than that value.

Likelihood Considerations

- The ballpark probabilities previously described are normally associated with the "initiator" node of an event tree.

- There are many more nodes (branches) on a given event tree associated with the facility response.

- The factors increasing or decreasing the likelihood of each node can be used to adjust the likelihood that the initiating event will actually lead to a dam failure, and thereby build the case for the likelihood category that best fits the given potential failure mode.

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Confidence

- We can also assign a confidence to qualitative estimates of PFM likelihood

- Confidence: High, Moderate, and Low Confidence

Confidence

- High confidence in a likelihood estimate means we are unlikely to revise our estimate with more information.

- Low confidence means we are likely to revise our estimate with more information

- Moderate confidence means we are unsure about the potential to change the estimate

DISCUSSION/QUESTIONS?

Consequences

- Three primary physical factors affect potential life loss in dam failure scenarios:

  - the number of people occupying the area inundated by a dam-break flood,

  - the amount of warning provided in relation to the time required to move to a safe location,

  - and the intensity of the flow to which people are ultimately exposed.

Population at Risk (PAR)

- The methods for the PAR estimates will be further discussed on Day 2 of this workshop.

- For relatively small populations, the PAR can be estimated by hand (for example, a town's population can be multiplied by the percentage of that town that is inundated).

- An estimate of 3 persons per residence (more for larger, nonresidential structures) is often used to roughly estimate the downstream PAR.

- Additional consideration should be given to other day and night use of facilities within the inundation area such as transitory hikers, campers, workers, etc.

Population at Risk

- However, automated processes are usually used to count population at risk for higher levels of study when the threatened population is large.

- Requirements:
  - flood routing studies converted into GIS format
  - census data

Possible Life Loss (PLL)

- Survivability (PLL) is determined by two factors:
  - Warning Timing
  - Flood Severity

Warning Time

- Past dam-break flood instances show that, in general, the number of fatalities decreases as the distance downstream increases

- Potential life loss decreases when the travel time begins to exceed the amount of time required to warn and evacuate the population at risk

- A combination of breach development rate and flood wave velocity determines the flood wave arrival time for a given distance.

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Flood Severity

- Modified from Graham, a simplified method, used for the SLPRA, dam break flood severity is divided into three categories:
  - Low
  - Medium
  - High
- Severities are determined using Depth Velocity (DV). This criterion is meant to reflect the power of the flood water to affect residential structures (not pedestrians).
- DV is obtained by dividing the breach outflow by the cross section topwidth.

Consequence Adjustment Factors

	Low Flood Severity (No buildings washed off foundation, less that 10-foot depth of flooding) DV < 50	Medium Flood Severity (Homes destroyed but trees or mangled homes remain, greater than 10-foot depth of flooding) DV > 50	High Flood Severity (Instantaneous dam failure, inundation area swept clean of structures, deep flood depth reached very quickly)
No Warning (Excess response time less than 15 minutes)	0.01	0.15	0.75
Some Warning (Excess response time 15 to 60 minutes)	0.005	0.03	0.4
More Warning (Excess response time Greater than 60 minutes)	0.0003	0.02	0.2

Potential Life Loss (PLL) Estimates

- The consequence adjustment factors for the appropriate combination are multiplied by the estimated PAR to provide an estimate of potential (human) life loss.

- The total PLL is computed and used to determine the appropriate consequence category using the table listed below.

- This table was also used in the SLPRA tool.

Consequences 0-6 | Consequences 7-11

Possible Life Loss	General Description	Consequence Category
1-10	• Direct loss of human life possible, related primarily to difficulties in warning and evacuating recreationists and few scattered individual houses close to the dam or downstream population centers with extensive warning time. • Minor to significant damage to permanently occupied structures, roadways and bridges throughout the inundation zone (~$50 to $100 M). • Local to regional disruption of essential facilities and access. • Medium environmental damage • Less than 1 year recovery.	7
10-100	• Loss of human life is expected due to the severity of the flooding and nearby population centers (10-100 people). • Downstream discharges result in significant property damage (~$100 M to $500 M) • Regional disruption of essential facilities and access. • Significant environmental damage • 1 - 2 year recovery .	8
100-1000	• Significant loss of human life is expected due to the severity of the flooding and moderate population affected within close proximity of the dam. • Significant property damage over a large area (~$500 M to $1 B)... • Multi-regional disruption of essential facilities and access. • Large environmental damage • Multi-year recovery 2-5 years	9

Consequences 0-6 | Consequences 7-11

Possible Life Loss	General Description	Consequence Category
1000-10,000	• High loss of human life is expected due to the severity of the flooding and moderate population affected within close proximity of the dam. • Large property damage over a large area (> $1 B). • Multi-state to Multi-regional disruption of essential facilities and access. • Large environmental damage, some permanent. • Recovery over an very long time (5-10 years)	10
>10,000	• Extreme loss of human life is expected due to the severity of the flooding and large population affected. • Extreme property damage would be incurred over a large area (> $10 B). • Massive environmental mitigation cost or impossible to mitigate. • National to Multi-state disruption of essential facilities and access. • Recovery over an extreme length of time (10 to 20 years).	11

QRA PLL Estimates

- For a QRA the simplified consequence analysis may suffice for simpler downstream areas

- However, for many analyses, more sophisticated analyses might be required

- The Corps of Engineers (COE) program HEC-FIA is a program that can be used for better PLL estimates

- QRA generally needs at least generic HEC-FIA estimates.

RISK

- Choose a Consequence category and plot this result on the chart listed below again taken from the SLPRA.

Failure

Likelihood

Category

	0-6	7	8	9	10	11
Very High	Yellow	Red	Red	Red	Red	Red
High	Yellow	Red	Red	Red	Red	Red
Moderate	Yellow	Yellow	Yellow	Red	Red	Red
Low	Green	Green	Yellow	Yellow	Red	Red
Very Low	Green	Green	Green	Yellow	Yellow	Red
Remote	Green	Green	Green	Green	Yellow	Yellow

Consequence Category

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RISK

- For example, use a Likelihood category of **Low** and a Consequence Category of **9** (100 to 1000 PLL).

- Let's look at the tables again to remember what this means and plot this on the chart

Likelihood of Failure

Category	General Description	APF
Remote	The physical conditions do not exist for its development or the likelihood is so remote. Several events must occur concurrently or in series to trigger failure. Most, if not all of the events are very unlikely. Or, it would likely take a flood or earthquake with a return period of more than 1,000,000 years to trigger the potential failure mode.	$< 10^{-6}$
Very Low	The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred or that a condition or flaw exists that could lead to its development. Or, a flood or earthquake with a return period of between 200,000 and 1,000,000 years would likely trigger the potential failure mode.	10^{-5}
Low	**The fundamental condition or defect is known to exist, indirect evidence suggests it is plausible, but evidence is weighted more heavily toward unlikely than likely. Or, a flood or earthquake with a return period between 20,000 and 100,000 years would likely trigger the potential failure mode.**	10^{-4}

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Consequence Table

Consequences 0-6	Consequences 7-11

Possible Life Loss	General Description	Consequence Category
100-1000	• Significant loss of human life is expected due to the severity of the flooding and moderate population affected within close proximity of the dam. • Significant property damage over a large area (~$500 M to $1 B)... • Multi-regional disruption of essential facilities and access. • Large environmental damage • Multi-year recovery 2-5 years	9

Failure Likelihood Category vs Consequence Category risk matrix

Failure Likelihood Category (rows, top to bottom): Very High, High, Moderate, Low, Very Low, Remote

Consequence Category (columns): 0-6, 7, 8, 9, 10, 11

X is located at Low likelihood / Consequence Category 9.

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Confidence

- We can also assign a confidence to qualitative estimates of consequence

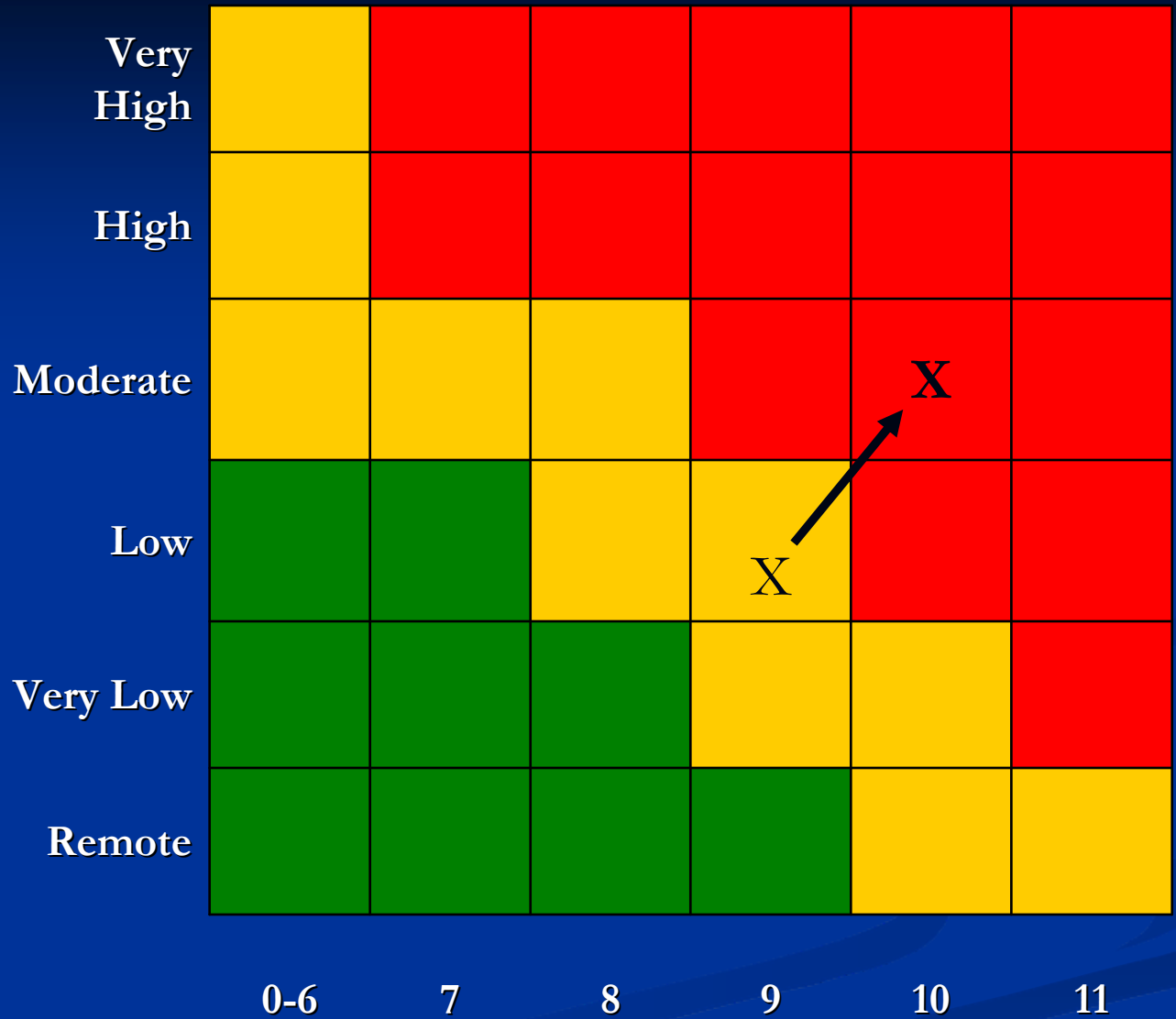- Confidence: High, Moderate, and Low Confidence

Confidence

- Say we have low confidence in our estimates of either likelihood or consequence

- If our likelihood estimate would be **Moderate** with more information, we might recommend further investigation of the PFM

- If our consequence estimate might be more than 1000 people **(Category 10),** we might use a higher level consequence tool to estimate the PLL

DISCUSSION/QUESTIONS?