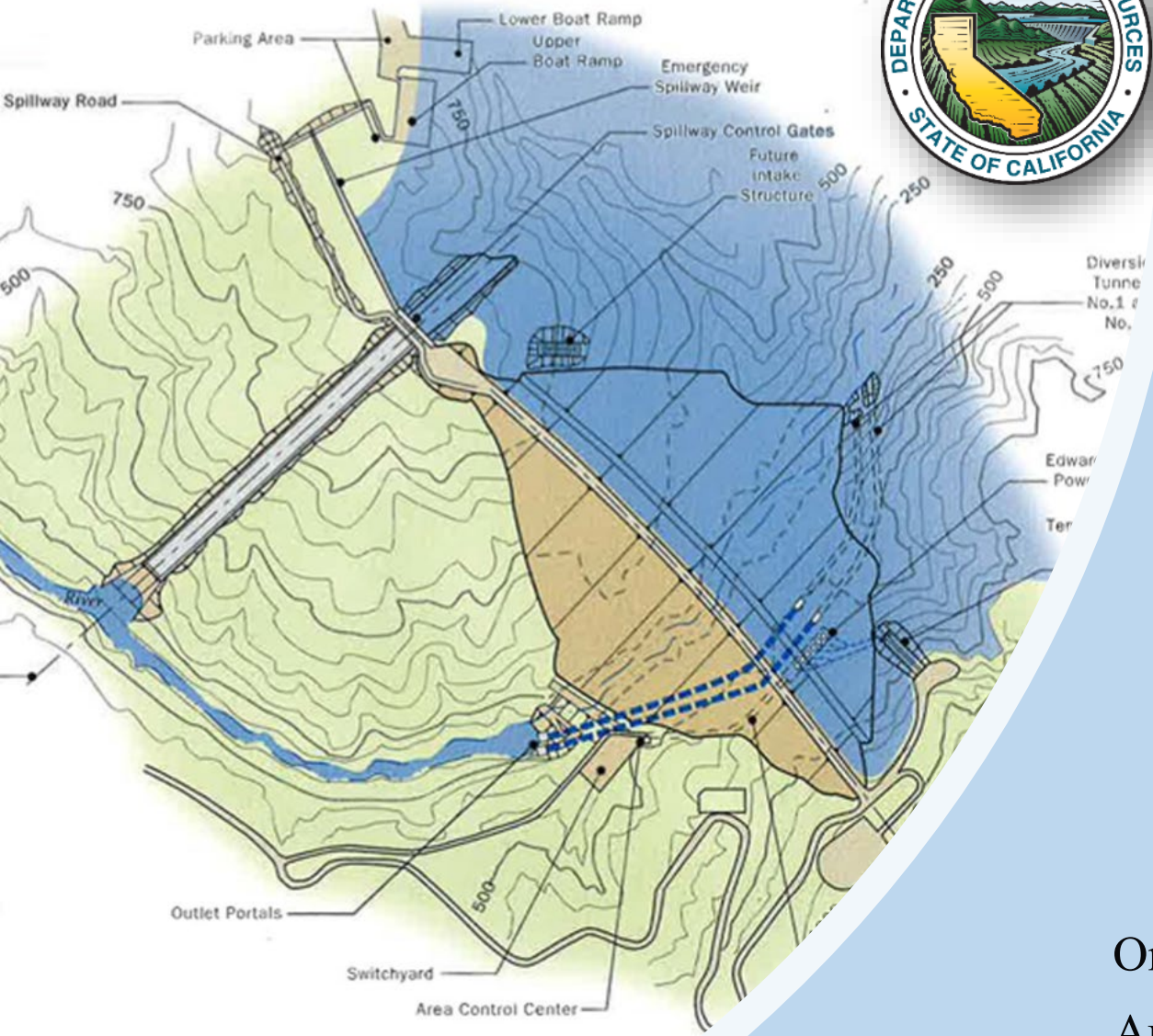


STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
**OROVILLE DAM SAFETY**
**COMPREHENSIVE NEEDS ASSESSMENT**

# Update on CNA PFM Development and Existing Conditions Assessment

Oroville Dam Safety – Ad Hoc Committee Meeting No. 5

August 9, 2019

# Update on CNA PFM Development and CNA Existing Conditions Assessment

## Presentation Outline

- **Background**
  - Review:  Purpose of the CNA
  - Risk-Informed Decision Making Approach
  - Ongoing Independent Level 2 Risk Analysis
  - Need for CNA Existing Conditions Assessment
- **Overview of CNA Existing Conditions Assessment**
  - PFM Development and Evaluation
  - Examples of PFM Development
  - Comparisons of Estimated PFM Likelihoods with L2RA Estimates
  - Preliminary Results to Date

# Update on CNA PFM Development and CNA Existing Conditions Assessment

## Presentation Outline

- **Background**
  - Review: Purpose of the CNA
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  - Ongoing Independent Level 2 Risk Analysis
  - Need for CNA Existing Conditions Assessment
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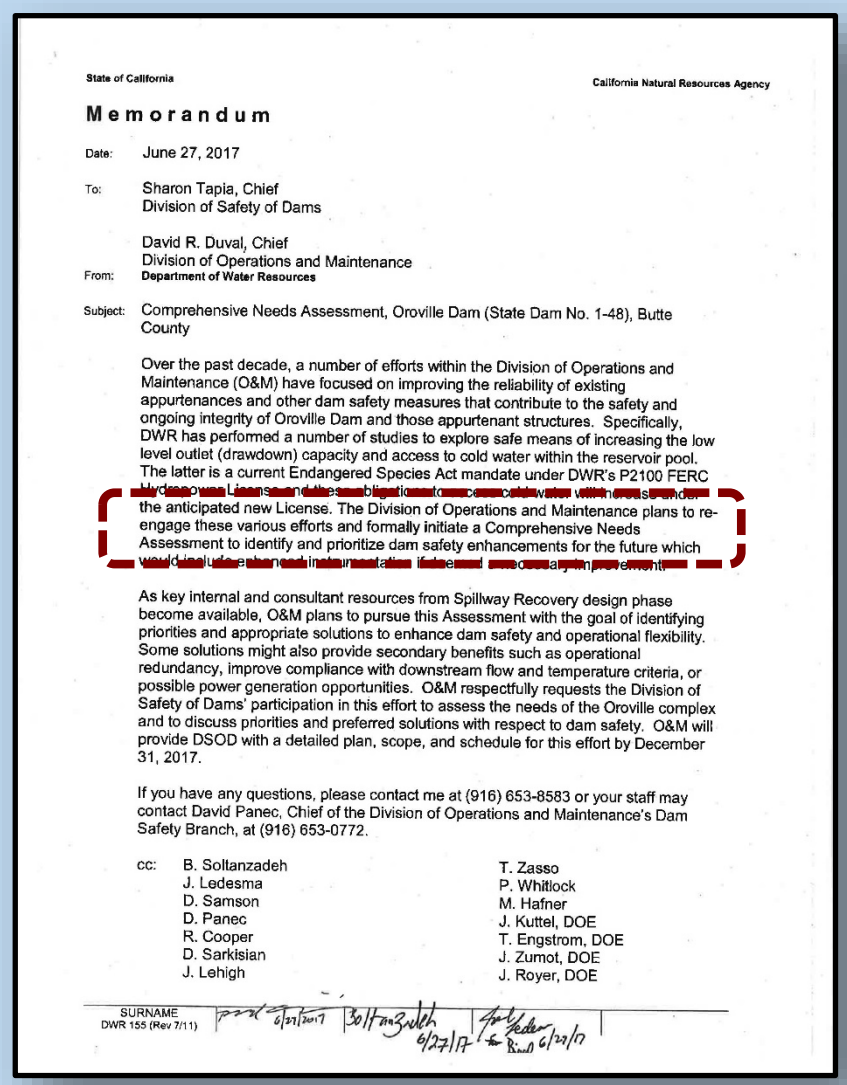
  - Examples of PFM Development
  - Comparisons of Estimated PFM Likelihoods with L2RA Estimates
  - Preliminary Results to Date

# Review: Purpose of the Comprehensive Needs Assessment

- **Identify and prioritize dam safety enhancements**
  - ✓ Document existing conditions
  - ✓ Identify current **dam safety** risks

- **Identify risk reduction measures to bolster safety and reliability**
  - ✓ Develop prioritized list of safety and reliability needs
  - ✓ Provide set of Alternative Plans to DWR management to consider in future investment

# Initial Commitment for Comprehensive Needs Assessment



State of California — California Natural Resources Agency

**Memorandum**

Date: June 27, 2017

To: Sharon Tapia, Chief
Division of Safety of Dams

From: David R. Duval, Chief
Division of Operations and Maintenance
**Department of Water Resources**

Subject: Comprehensive Needs Assessment, Oroville Dam (State Dam No. 1-48), Butte County

Over the past decade, a number of efforts within the Division of Operations and Maintenance (O&M) have focused on improving the reliability of existing appurtenances and other dam safety measures that contribute to the safety and ongoing integrity of Oroville Dam and those appurtenant structures. Specifically, DWR has performed a number of studies to explore safe means of increasing the low level outlet (drawdown) capacity and access to cold water within the reservoir pool. The latter is a current Endangered Species Act mandate under DWR's P2100 FERC Hydroelectric License and the obligation to access cold water within the pool under the anticipated new License. The Division of Operations and Maintenance plans to re-engage these various efforts and formally initiate a Comprehensive Needs Assessment to identify and prioritize dam safety enhancements for the future which would include the evaluation, implementation, if deemed cost effective, of secondary improvement.

As key internal and consultant resources from Spillway Recovery design phase become available, O&M plans to pursue this Assessment with the goal of identifying priorities and appropriate solutions to enhance dam safety and operational flexibility. Some solutions might also provide secondary benefits such as operational redundancy, improve compliance with downstream flow and temperature criteria, or possible power generation opportunities. O&M respectfully requests the Division of Safety of Dams' participation in this effort to assess the needs of the Oroville complex and to discuss priorities and preferred solutions with respect to dam safety. O&M will provide DSOD with a detailed plan, scope, and schedule for this effort by December 31, 2017.

If you have any questions, please contact me at (916) 653-8583 or your staff may contact David Panec, Chief of the Division of Operations and Maintenance's Dam Safety Branch, at (916) 653-0772.

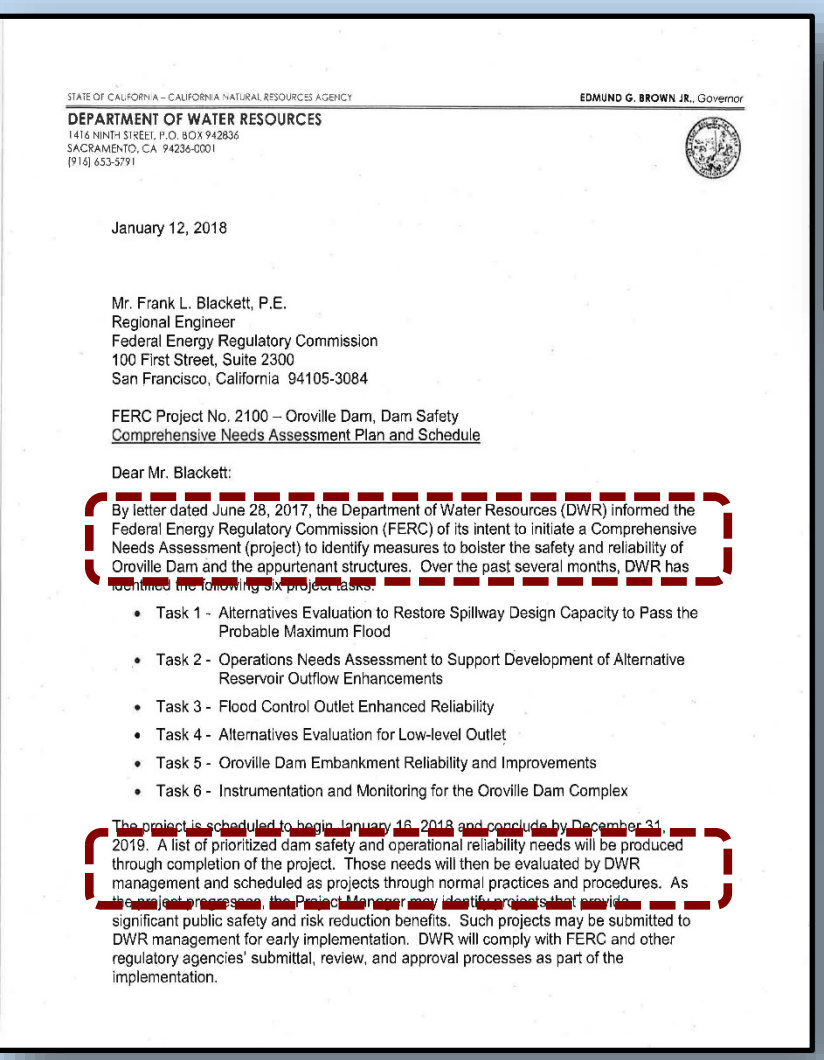
cc: B. Soltanzadeh
J. Ledesma
D. Samson
D. Panec
R. Cooper
D. Sarkisian
J. Lehigh
T. Zasso
P. Whitlock
M. Hafner
J. Kuttel, DOE
T. Engstrom, DOE
J. Zumot, DOE
J. Royer, DOE

SURNAME
DWR 155 (Rev 7/11)

The Division of Operations and Maintenance plans to re-engage these various efforts and formally initiate a Comprehensive Needs Assessment to identify and prioritize dam safety enhancements for the future

**June 27 and 28, 2017 DWR Letters to FERC and DSOD**

# Initial Outline of Comprehensive Needs Assessment



STATE OF CALIFORNIA – CALIFORNIA NATURAL RESOURCES AGENCY — EDMUND G. BROWN JR., Governor

DEPARTMENT OF WATER RESOURCES
1416 NINTH STREET, P.O. BOX 942836
SACRAMENTO, CA 94236-0001
(916) 653-5791

January 12, 2018

Mr. Frank L. Blackett, P.E.
Regional Engineer
Federal Energy Regulatory Commission
100 First Street, Suite 2300
San Francisco, California 94105-3084

FERC Project No. 2100 – Oroville Dam, Dam Safety
Comprehensive Needs Assessment Plan and Schedule

Dear Mr. Blackett:

By letter dated June 28, 2017, the Department of Water Resources (DWR) informed the Federal Energy Regulatory Commission (FERC) of its intent to initiate a Comprehensive Needs Assessment (project) to identify measures to bolster the safety and reliability of Oroville Dam and the appurtenant structures. Over the past several months, DWR has identified the following six project tasks:

- Task 1 - Alternatives Evaluation to Restore Spillway Design Capacity to Pass the Probable Maximum Flood
- Task 2 - Operations Needs Assessment to Support Development of Alternative Reservoir Outflow Enhancements
- Task 3 - Flood Control Outlet Enhanced Reliability
- Task 4 - Alternatives Evaluation for Low-level Outlet
- Task 5 - Oroville Dam Embankment Reliability and Improvements
- Task 6 - Instrumentation and Monitoring for the Oroville Dam Complex

The project is scheduled to begin January 16, 2018 and conclude by December 31, 2019. A list of prioritized dam safety and operational reliability needs will be produced through completion of the project. Those needs will then be evaluated by DWR management and scheduled as projects through normal practices and procedures. As the project progresses, the Project Manager may identify projects that provide significant public safety and risk reduction benefits. Such projects may be submitted to DWR management for early implementation. DWR will comply with FERC and other regulatory agencies' submittal, review, and approval processes as part of the implementation.

By letter dated June 28, 2017, the Department of Water Resources (DWR) informed the Federal Energy Regulatory Commission (FERC) of its intent to initiate a Comprehensive Needs Assessment (project) to identify measures to bolster the safety and reliability of Oroville Dam and the appurtenant structures.

A list of prioritized dam safety and operational reliability needs will be produced through completion of the project. Those needs will then be evaluated by DWR management and scheduled as projects through normal practices and procedures.

**January 12, 2018 DWR Letter to FERC**

# Final Product of Comprehensive Needs Assessment

**A report documenting an Existing Conditions Assessment that identifies current Dam Safety risks at the Oroville Dam complex, opportunities to reduce risk, and a set of Alternative Plans that DWR could consider for future implementation for risk reduction.**

# Update on CNA PFM Development and CNA Existing Conditions Assessment

## Presentation Outline

- **Background**
  - Review:  Purpose of the CNA
  - **Risk-Informed Decision Making Approach**
  - Ongoing Independent Level 2 Risk Analysis
  - Need for CNA Existing Conditions Assessment
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  - PFM Development and Evaluation
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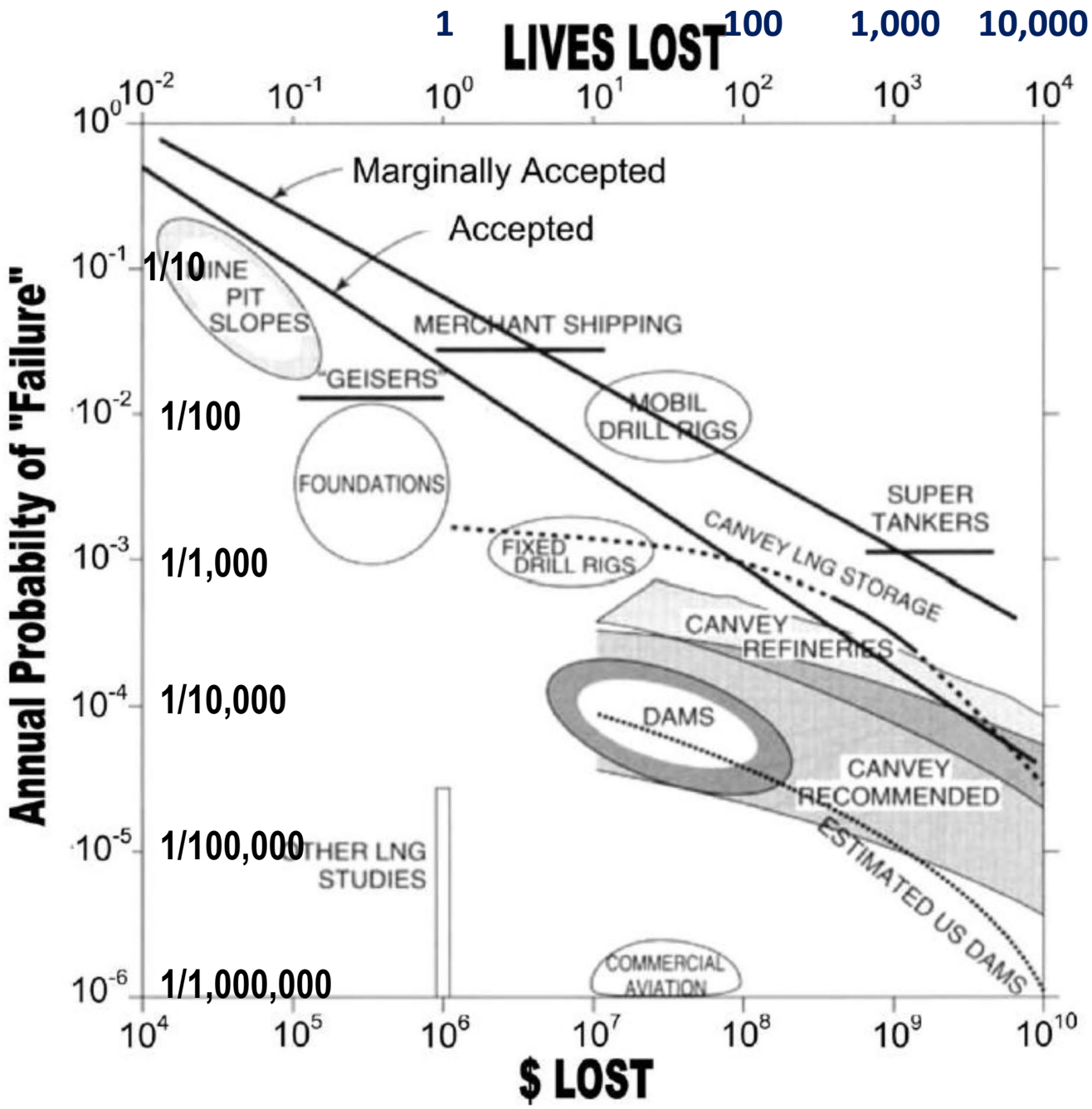
# Comprehensive Needs Assessment will employ Risk-Informed Decision Making (RIDM) Processes

The RIDM approach is the process of making safety decisions by evaluating if existing risks are tolerable and present risk measures are adequate, and if not, whether alternative risk reduction measures are justified.

(FEMA, 2015)

Risk = product of the likelihood of an adverse event and the consequences of that event

(U.S. Bureau of Reclamation, 2003)




# Tolerable Levels of Risk for Different Industries/ Facilities

from T. William Lambe and W. Allen Marr

# RIDM Process – Step 1
# Assess and Compare Risks:
# Potential Failure Mode Analyses

- ✓ Identify possible scenarios (Potential Failure Modes) that would lead to adverse impacts
- ✓ Estimate the likelihood of each scenario occurring
- ✓ Estimate the consequences of each scenario
- ✓ Estimate Risk = Likelihood x Consequence
- ✓ Compare risk across scenarios to help prioritize future risk reduction measures

# Use of Potential Failure Modes (PFMs) in Dam Safety Risk Evaluations

- **Potential Failure Mode Analyses (PFMA):**
  - ✓ Required by FERC since December 2002
  - ✓ To be conducted jointly by Owner, Independent Consultant, and FERC staff

from Chapter 14, *Dam Safety Monitoring Program*, Revision 3, May 2017, FERC

**Potential Failure Mode (PFM)**

The chain of events leading to unsatisfactory performance of the dam or a portion thereof. The dam does not have to completely fail in the sense of a complete release of the impounded water. Failure Modes that result in unintended releases of water, such as the Folsom Dam radial gate failure, are also considered.

**Potential Failure Mode Analysis (PFMA)**

The process utilized to determine the Potential Failure Modes pertinent to the dam under investigation.

# Use of Potential Failure Modes (PFMs) in Dam Safety Risk Evaluations

## ➢ Potential Failure Mode Analyses (PFMA):

### ✓ Consideration and Development of PFMs – Example: Progression of Internal Erosion PFM

Reservoir at or above threshold level

**Initiation – Erosion starts**

Continuation – Unfiltered or inadequately filtered exit exists

Progression – Continuous stable roof and/or sidewalls

Progression – Constriction or upstream zone fails to limit flows

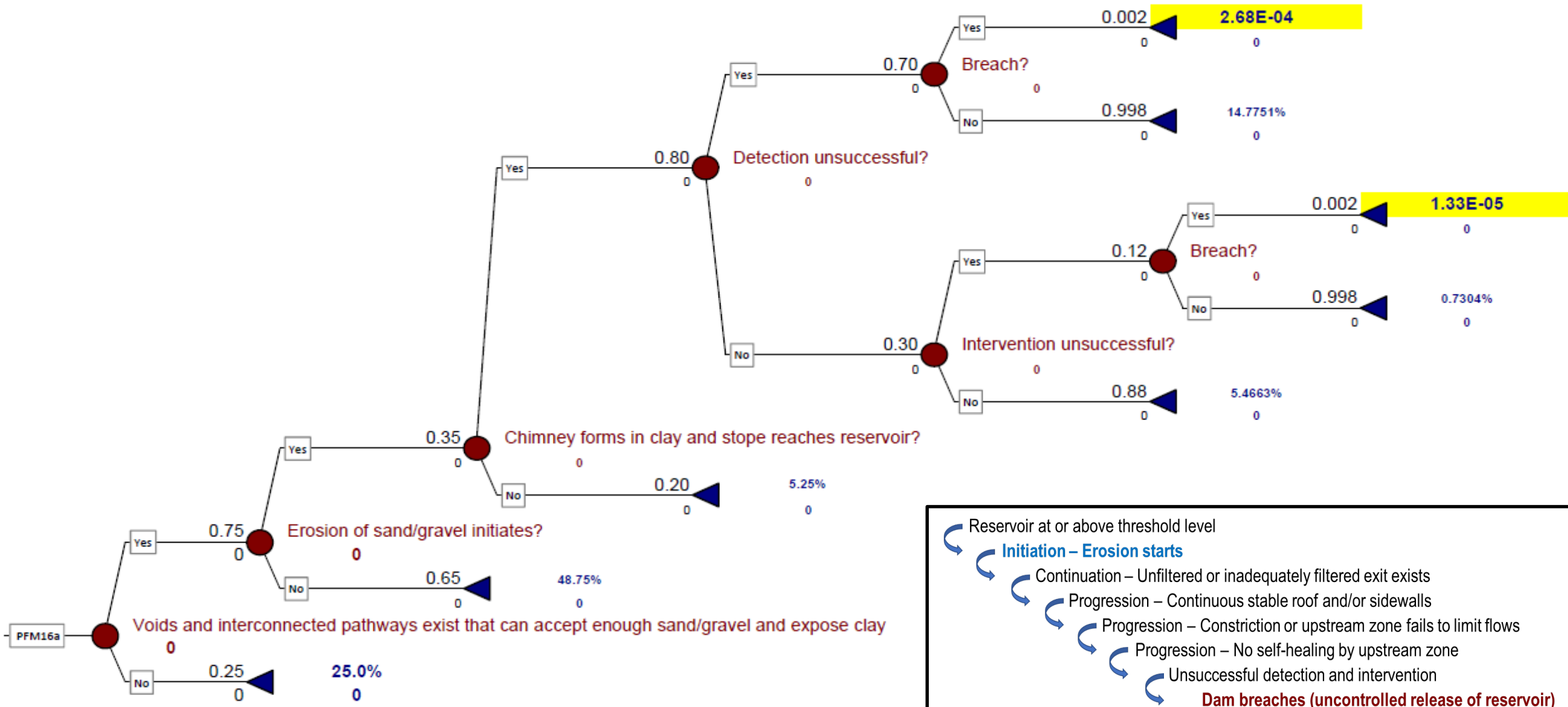
Progression – No self-healing by upstream zone

Unsuccessful detection and intervention

**Dam breaches (uncontrolled release of reservoir)**

from "*Best Practices in Dam and Levee Safety Risk Analysis*," United States Bureau of Reclamation and Army Corps of Engineers

# Event Tree/Nodal Approach for Likelihood Estimates

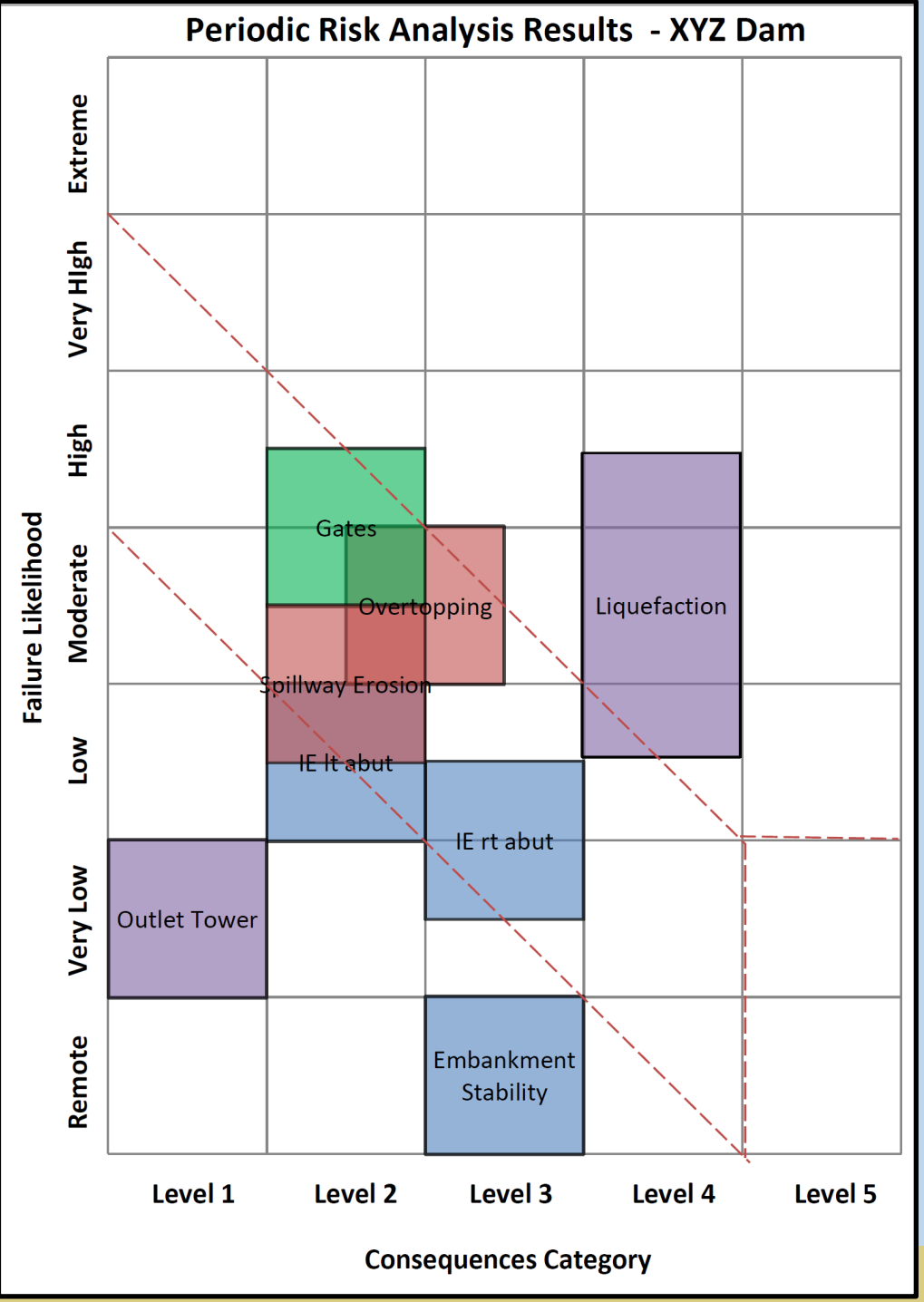



- Reservoir at or above threshold level
  - **Initiation – Erosion starts**
    - Continuation – Unfiltered or inadequately filtered exit exists
      - Progression – Continuous stable roof and/or sidewalls
        - Progression – Constriction or upstream zone fails to limit flows
          - Progression – No self-healing by upstream zone
            - Unsuccessful detection and intervention
              - **Dam breaches (uncontrolled release of reservoir)**

# Qualitative Approach to Estimate Failure Likelihood using Descriptors

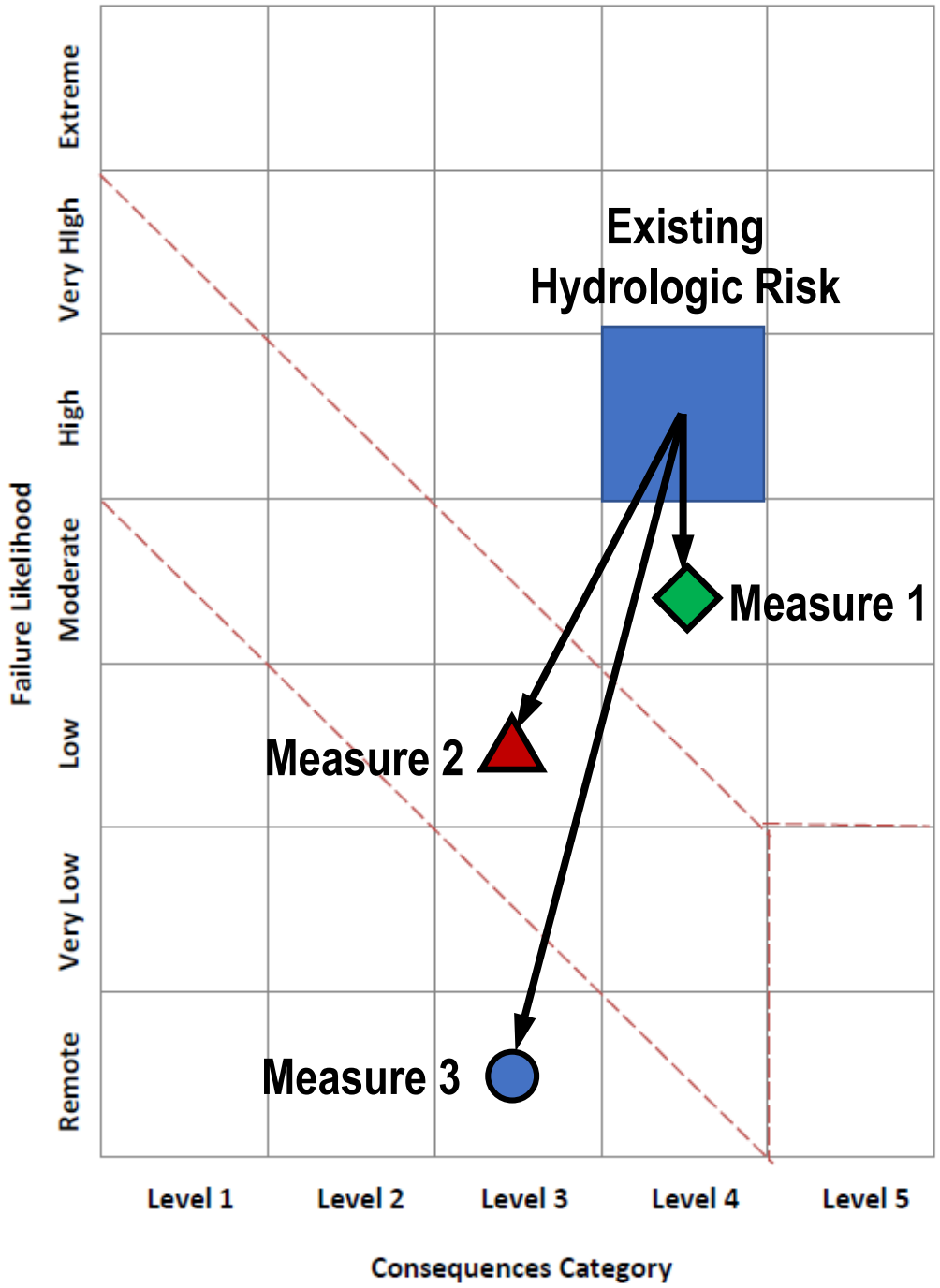
| Failure Likelihood Descriptors | | |
|---|---|---|
| **Failure Likelihood Descriptors** | **Annual Failure Likelihood** | **Evidence** |
| Certain | More frequent (greater) than 1/10 | There is direct evidence or substantial indirect evidence to suggest it certain to nearly certain that failure is eminent or extremely likely in the next few years. |
| Extreme | 1/10 to 1/100 | There is direct evidence or substantial indirect evidence to suggest that failure has initiated or is very likely to occur during the life of the structure. |
| Very High | 1/100 to 1/1,000 | There is direct evidence or substantial indirect evidence to suggest that failure has initiated or is likely to occur. |
| High | 1/1,000 to 1/10,000 | The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward “more likely” than “less likely.” |
| Moderate | 1/10,000 to 1/100,000 | The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward “less likely” than “more likely.” |
| Low | 1/100,000 to 1/1,000,000 | The possibility cannot be ruled out, the fundamental condition or defect is postulated. Evidence indicates it is very unlikely. |
| Very Low | 1/1,000,000 to 10,000,000 | 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 initiation. |
| Remote | More remote (less) than 1/10,000,000 | Several events must occur concurrently or in series to cause failure, and most, if not all, have negligible likelihood such that the failure likelihood is negligible. |

from FERC, 2018




# Example of Periodic (Level 2) Risk Analysis Matrix for Societal Incremental Life Safety

from FERC Risk-Informed Decision Making for Dam Safety, Periodic (Level 2) Risk Analysis Procedures, DRAFT, Version 1.1, June 2018




# Example Use of Periodic (Level 2) Risk Analysis Matrix for Evaluating Risk Reduction Measures

Adapted from FERC Risk-Informed Decision Making for Dam Safety, Periodic (Level 2) Risk Analysis Procedures, DRAFT, Version 1.1, June 2018

# Update on CNA PFM Development and CNA Existing Conditions Assessment

## Presentation Outline

- **Background**
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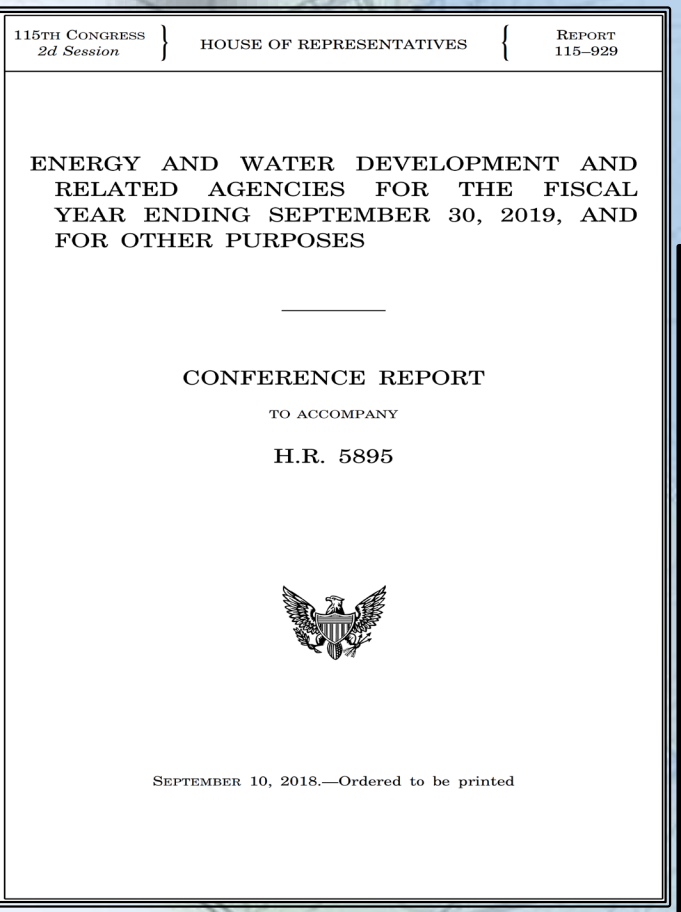
# Congressional Mandate for Level 2 Risk Analysis as part of Part12D Safety Review of Oroville Dam

## HR 5895 CONFERENCE REPORT – September 20, 2018



115TH CONGRESS 2d Session | HOUSE OF REPRESENTATIVES | REPORT 115–929

ENERGY AND WATER DEVELOPMENT AND RELATED AGENCIES FOR THE FISCAL YEAR ENDING SEPTEMBER 30, 2019, AND FOR OTHER PURPOSES

CONFERENCE REPORT

TO ACCOMPANY

H.R. 5895

SEPTEMBER 10, 2018.—Ordered to be printed

FEDERAL ENERGY REGULATORY COMMISSION

SALARIES AND EXPENSES

The agreement provides $369,900,000 for the Federal Energy Regulatory Commission (FERC). Revenues for FERC are set to an amount equal to the budget authority, resulting in a net appropriation of $0.

FERC shall require the licensee of Oroville Dam to request the United States Society on Dams to nominate independent consultants to prepare a level 2 risk analysis, consistent with the Commission's guidelines, for use in conducting the next Part 12 safety review of Oroville Dam, currently scheduled for 2019. FERC shall ensure the independence of the nominated consultants from the licensee.

# Update on Level 2 Risk Analysis and CNA Existing Conditions Assessment

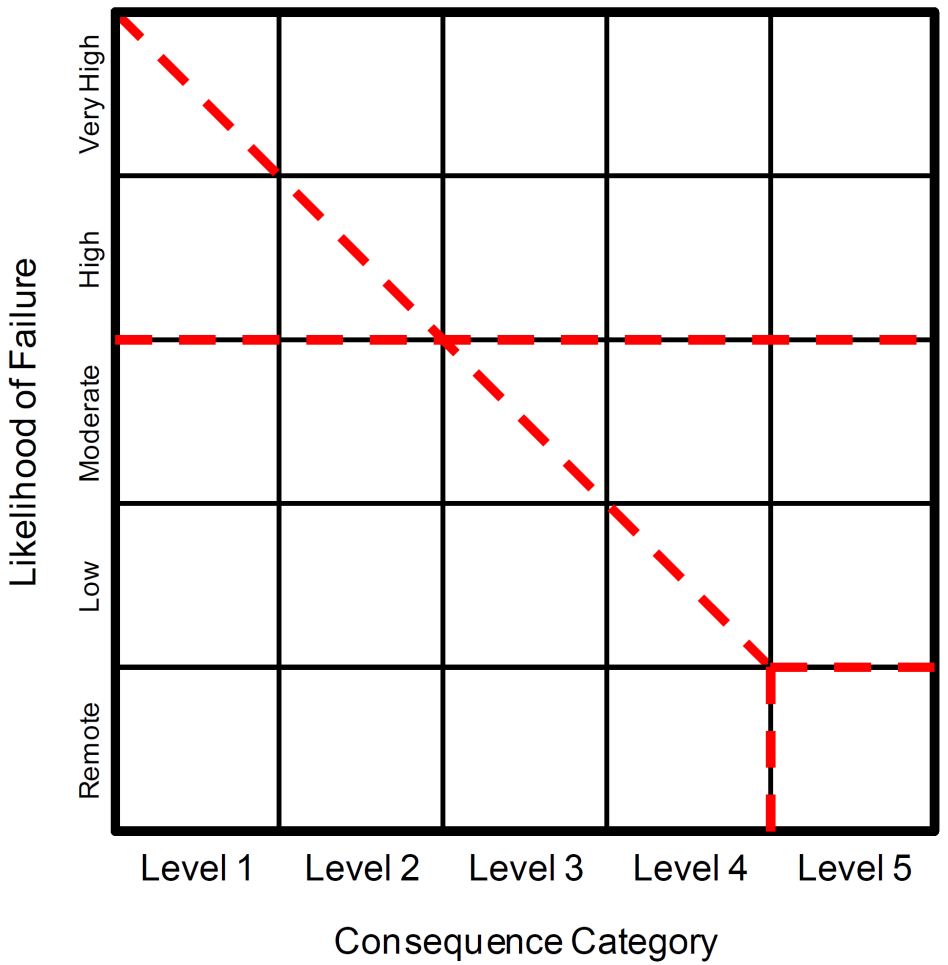
**Table 1 - Categories of Identified Potential Failure Modes**

*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.* Note that even though these potential failure modes are considered less significant than Category I they are all also described and included with reasons for and against the occurrence of the potential failure mode. The reason for the lesser significance is noted and summarized in the documentation report or notes.

*Category III - More Information or Analyses are needed in order to classify these potential failure modes to some degree lacked information to allow a confident judgment of significance and thus a dam safety investigative action or analyses can be recommended. Because action is required before resolution the need for this action may also be highlighted.*

*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.*




**from Section I-4 Semi-Quantitative Risk Analysis, USBR/USACE Best Practices (04-13-15)**

# Level 2 Risk Analysis

## Organization, Leadership, and Participants:

- ***Independent Team Participants*** include experts from 9 different consulting firms and agencies include:

| | | |
|---|---|---|
| ✓ Robin Fell | (Geotechnical) | University of New South Wales, Australia |
| ✓ David Paul | (Geotechnical) | HDR (formerly USACE Risk Management Center) |
| ✓ Mark Stanley | (Geotechnical) | HDR |
| ✓ Dan Osmun | (Geotechnical) | HDR (formerly USBR) |
| ✓ Elena Sossenkina | (Geotechnical) | HDR |
| ✓ Keith Kelson | (Geology/Seismology) | USACE Risk Management Center |
| ✓ Chris Hitchcock | (Geology/Seismology) | Lettis Consultants International |
| ✓ Dina Hunt | (Geology/Seismology) | Gannett Fleming |
| ✓ Bill Cole | (Geology) | Sage Engineers |
| ✓ Alex Bjelica | (Structural) | Black & Veatch |
| ✓ Keith Moen | (Structural) | HDR |
| ✓ Phoebe Percell | (Structural) | HDR (formerly USBR) |
| ✓ Todd Schellhase | (Structural) | Black & Veatch |
| ✓ Tom Hepler | (Structural) | Schnabel Engineering (formerly USBR) |
| ✓ Nathan Pringle | (Hydrology/Hydraulics) | HDR |
| ✓ Paul Rischer | (Hydrology/Consequences) | HDR (formerly USACE Risk Management Center) |
| ✓ Jason Needham | (Consequences) | USACE Risk Management Center |
| ✓ Joe Goldstein | (Consequences) | Geosyntec (formerly USACE) |

# Level 2 Risk Analysis

## Organization, Leadership, and Participants:

- ***DWR Subject Matter Experts/Contributors*** provide design, construction, and performance information – participate in discussions and initial rankings of risk, but not in final Independent Evaluation – include:

| | | | | |
|---|---|---|---|---|
| ✓ | Leslie Harder | (Geotechnical) | HDR (formerly DWR) | |
| ✓ | Mitch Tyler | (Geotechnical) | DWR – DOE | |
| ✓ | Ryan Abernathy | (Civil/Geotechnical) | DWR - DOE | |
| ✓ | Daniel Cimini | (Civil/Geotechnical) | DWR - DOE | |
| ✓ | Holly Nichols | (Geology) | DWR – Project Geology | |
| ✓ | Nick Hightower | (Geology) | DWR – Project Geology | |
| ✓ | Sean Dunbar | (Geology) | DWR – Project Geology | |
| ✓ | Art Carleton | (Structural) | DWR – DOE | |
| ✓ | Cody Kimball | (Structural) | DWR – DOE | |
| ✓ | Kenny Dosanjh | (Structural) | HDR (on behalf of DWR) | |
| ✓ | Dustin Jones | (Hydrology/Hydraulics) | DWR – Project Operations | CNA Task 2 Lead |
| ✓ | David Panec | (Performance/Surveillance) | DWR – Dam Safety Branch | CNA Task 6 Lead |
| ✓ | Paul Dunlap | (Performance/Surveillance) | DWR – Dam Safety Branch | |
| ✓ | Gina House | (Operations) | DWR – Oroville Field Division Operations | |
| ✓ | Clint Womack | (Operations) | DWR – Oroville Field Division Operations | |
| ✓ | Jeff House | (Operations) | DWR – Oroville Field Division Plant Maintenance | |

# Level 2 Risk Analysis

## Organization, Leadership, and Participants:

- ***Oversight*** **provided by FERC, USACE, and DSOD staff, as well as by Eric Halpin, former Chief of Levee and Dam Safety for United States Army Corps of Engineers - participate in discussions, but do not vote on risk determinations - include:**

| | |
|---|---|
| ✓ Eric Halpin | Halpin Consulting (formerly Chief of Levee and Dam Safety, USACE) |
| ✓ Steven Townsley | USACE Risk Management Center |
| ✓ Frank Blackett | FERC – Regional Engineer |
| ✓ Doug Boyer | FERC – National Risk Analysis Lead |
| ✓ Vinh Tran | FERC |
| ✓ Dustin Smith | FERC |
| ✓ Eric Kennedy | FERC |
| ✓ Daniel Meyersohn | DSOD |
| ✓ Bill Pennington | DSOD |
| ✓ Wallace Lam | DSOD |
| ✓ Robert Jaeger | DSOD |
| ✓ Harpreet Hansra | DSOD |

# Level 2 Risk Analysis

## Organization, Leadership, and Participants:

- ***10th Part 12D Independent Consultant*** **participate in discussions, but do not vote on risk determinations:**
  - ✓ **Dr. Lelio Mejia — Geosyntec Consultants – also IRB Member**
  - ✓ **Dr. David Bowles — RAC Engineers and Economists**
  - ✓ **Drew Kennedy — Sage Engineers**

# Level 2 Risk Analysis

## Organization, Leadership, and Participants:

- ***Observers*** **include CNA Task Team Leads and IRB members – generally do not participate in discussions or vote on risk determinations - include:**
  - ✓ Sergio Escobar — DWR - CNA Project Manager
  - ✓ David Ford — HDR - CNA Project Integration Team
  - ✓ Craig Hall — GEI - CNA Task 1 Lead
  - ✓ Bob Filgas — HDR - CNA Task 3 Lead
  - ✓ Chris Krivanec — HDR - CNA Task 4 Lead
  - ✓ Bailey Johnson — HDR - CNA Task 4 Asst. Lead
  - ✓ Tim Wehling — DWR - CNA Task 5 Lead
  - ✓ Don Walker — DWR - O&M Asset Management

  - ✓ Daniel Wade — IRB Member


EXIT
ART
CARLTON
KEITH

# 171 Pre-Workshop PFMs Considered in Previous PFMA Workshops and Brainstorming Ideas Submitted by Level 2 Workshop Participants

- ✓ 35 PFMs (1 - 35) for Embankments
- ✓ 19 PFMs (36 – 52, 116, 117) Emergency Spillway
- ✓ 64 PFMs (53 – 115, 118) for FCO
- ✓ 53 PFMs (119 – 171) for Hyatt, Palermo, and RVOS outlets
- ✓ 171 PFMs Total

| PFM No. | No. | Dam | PFM Description | Loading | Component | Mechanism | CNA Task Team | PFM Group (A, B, C, D) | Previous Category | Submitter |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | Oroville Dam | CBND: foundation material | | | | 5 | | | |
| 2 | | Oroville Dam | CBND: grout curtain foundation | | | | 5 | | | |
| 3 | | Oroville Dam | CBND: | | | | 5 | | | |
| 4 | | Oroville Dam | CBND: earthqu | | | | 5 | | | |
| 5 | | Oroville Dam | CBND: shears in the dam foundation during seismic event. | | | Stability | 5 | | | |
| 6 | | Oroville Dam | CBND: Seismic damage to site access roads and bridges | Earthquake | Embankment | Dam Access | 5 | | | |
| 7 | | Oroville | | | | | | | | |
| 8 | | Oroville | | | | | | | | P. Risher |
| 9 | | Oroville | | | | | | | | C. Womack |
| 10 | H-3 | Oroville | | | | | | | 2 | |
| 11 | | Oroville | overtopping of Oroville Dam. | | | | | | | |
| 12 | | Oroville Dam | Internal erosion of fines from seepage barrier exiting into transition zone 2a due to imperfect filter compatibility. | Normal | Embankment | Internal Erosion | 5 | | | D. Panec |
| 13 | | Oroville Dam | Canyon Dam (Lake Almanor) upstream of Oroville Dam in Feather River Basin fails during normal loads, which leads to overtopping of Oroville Dam (variation of #4). | Normal | Embankment | Overtopping | 5 | A | | T. Hepler |
| 14 | | Oroville Dam | Toe Weir drain pipe becomes clogged, dam seepage cannot exit causing seepage to exit through dam fill materials | Normal | Embankment | Slope Instability | 5 | | | C. Womack |

# 171 Pre-Workshop PFMs Considered in Previous PFMA Workshops and Brainstorming Ideas Submitted by Level 2 Workshop Participants

| PFM No. | No. | Dam | PFM Description | Loading | Component | Mechanism | CNA Task Team | PFM Group (A, B, C, D) | Previous Category | Submitter |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | Oroville Dam | CBND: foundation material | | | | 5 | | | |
| 2 | | Oroville Dam | CBND: grout curtain foundation | | | | 5 | | | |
| 3 | | Oroville Dam | CBND: | | | | 5 | | | |
| 4 | | Oroville Dam | CBND: earthqu | | | | 5 | | | |
| 5 | | Oroville Dam | CBND: shears in the dam foundation during seismic event. | | | Stability | 5 | | | |
| 6 | | Oroville Dam | CBND: Seismic damage to site access roads and bridges | Earthquake | Embankment | Dam Access | 5 | | | |
| 7 | | Orovi | | | | | | | | |
| 8 | | Orovi | | | | | | | | P. Risher |
| 9 | | Orovi | | | | | | | | C. Womack |
| 10 | H-3 | Orovi | | | | | | | 2 | |
| 11 | | Orovi | overtopping of Oroville Dam. | | | | | | | |
| 12 | | Or | Internal erosion of fines from seepage barrier exiting into | | | Internal | | | | D. Panec |
| 13 | | Or | | | | | | | | T. Hepler |
| 14 | | Or | | | | | | | | C. Womack |

- ✓ 35 PFMs (1 - 35) for Embankments
- ✓ 19 PFMs (36 – 52, 116, 117) Emergency Spillway
- ✓ 64 PFMs (53 – 115, 118) for FCO
- ✓ 53 PFMs (119 – 171) for Hyatt, Palermo, and RVOS outlets
- ✓ 171 PFMs Total

- *Some PFMs – Previously Considered But Not Developed (CBND)*
- *Additional PFMs added during Level 2 Risk Analysis Workshop Sessions*

# Assigning Likelihood/Annual Probability of Failure for PFMs in Oroville Level 2 Risk Analysis

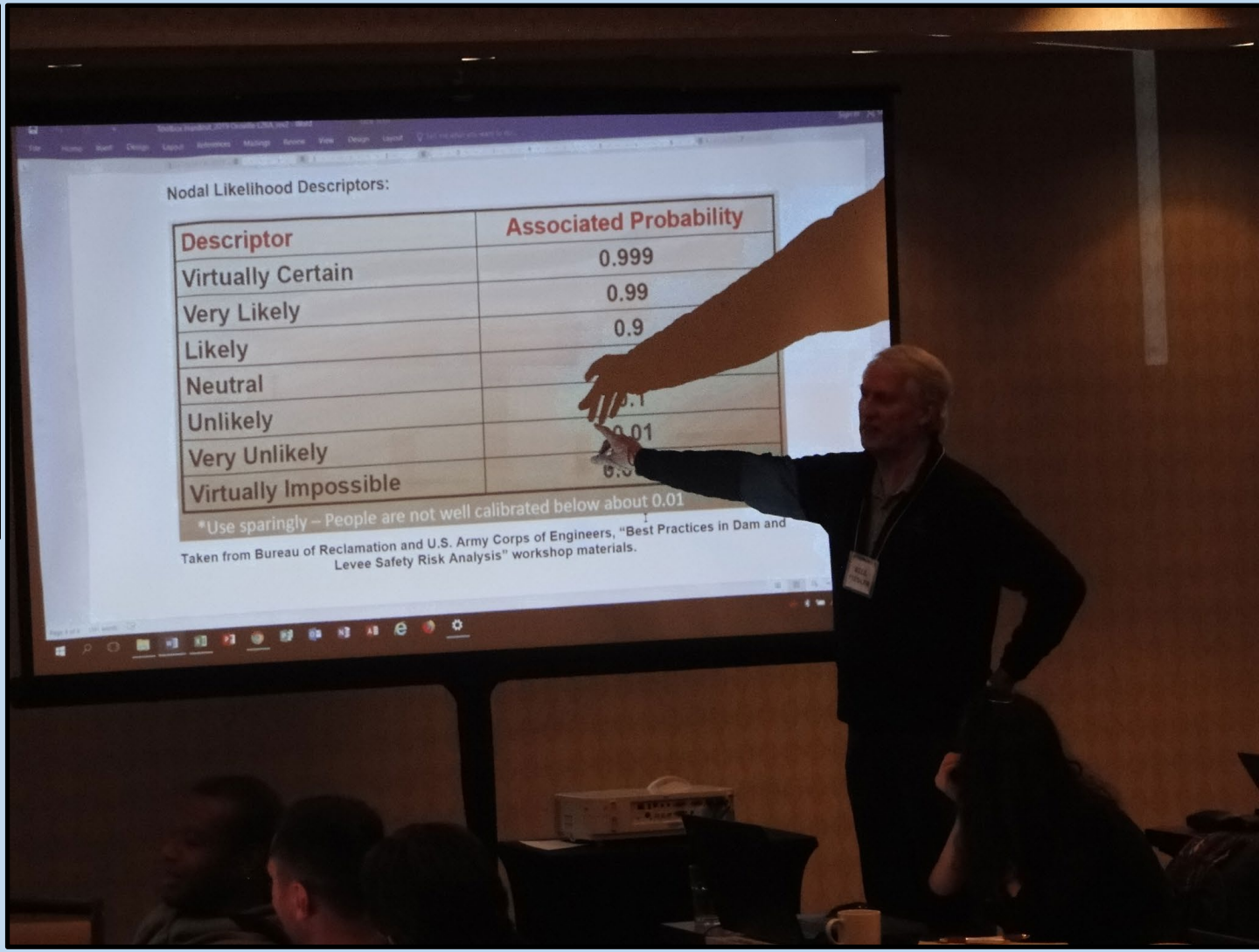
## L2RA Risk Matrix

| | |
|---|---|
| Very High | $10^{-3}$ - $10^{-2}$ |
| High | $10^{-4}$ - $10^{-3}$ |
| Moderate | $10^{-5}$ - $10^{-4}$ |
| Low | $10^{-6}$ - $10^{-5}$ |
| Very Low | $10^{-7}$ - $10^{-6}$ |
| Remote | < $10^{-7}$ |

Oroville Level 2 Risk Analysis Matrix

| Failure Likelihood Category | | | | | | | |
|---|---|---|---|---|---|---|---|
| Very High | | | | | | | $10^{-3}$ - $10^{-2}$ |
| High | | | | | | | $10^{-4}$ - $10^{-3}$ |
| Moderate | | | | | | | $10^{-5}$ - $10^{-4}$ |
| Low | | | | | | | $10^{-6}$ - $10^{-5}$ |
| Very Low | | | | | | | $10^{-7}$ - $10^{-6}$ |
| Remote | | | | | | | < $10^{-7}$ |
| | DWR AM Category 6 | DWR AM Category 7 | 8 | 9 | 10 | 11 | |
| | FERC Level 1 | FERC Level 2 | FERC Level 3 | FERC Level 4 | FERC Level 5 | | |
| Estimated Life Loss → | 0-1 | 1-10 | 10-100 | 100-1000 | 1,000 - 10,000 | > 10,000 | |

Incremental Life Loss Consequence Category




DO NOT MAKE ENTRIES IN RISK MATRIX

Make entries in the APF and Incremental Life- Loss Vectors if you judge this PFM to be physically possible

| APF | Failure Likelihood Category | Level 2 Risk Analysis Matrix - Breach | | | | | | APF Vector |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | APF |
| $10^{-3}$ - $10^{-2}$ | Very High | | | | | | | |
| $10^{-4}$ - $10^{-3}$ | High | | | | | | | |
| $10^{-5}$ - $10^{-4}$ | Moderate | | | | | | | |
| $10^{-6}$ - $10^{-5}$ | Low | | | 0.09 | 0.01 | | | 0.10 |
| $10^{-7}$ - $10^{-6}$ | Very Low | | | 0.72 | 0.08 | | | 0.80 |
| < $10^{-7}$ | Remote | | | 0.09 | 0.01 | | | 0.10 |
| Consequence Level | | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | | |
| Incremental Life Loss Consequence Category | | 0 - 1 | 1 - 10 | 10 - 100 | 100 - 1,000 | 1,000 - 10,000 | > 10,000 | a) 1.00 |
| Incremental Life Loss | | | | 0.90 | 0.10 | | | b) 1.00 |

Incremental Life- Loss Vector

| | | |
|---|---|---|
| If you judge this PFM to be not physically possible enter 1 (and do not make entries in APF and Incremental Life- Loss Vectors): | 0.00 | a) - c) must each sum to 1.00 (Except if PFM judged not physically possible in which case b) must be zero) c) 1.00 |

# Update on CNA PFM Development and CNA Existing Conditions Assessment

## Presentation Outline

- **Background**
  - Review:  Purpose of the CNA
  - Risk-Informed Decision Making Approach
  - Ongoing Independent Level 2 Risk Analysis
  - Need for CNA Existing Conditions Assessment
- **Overview of CNA Existing Conditions Assessment**
  - PFM Development and Evaluation
  - Examples of PFM Development
  - Comparisons of Estimated PFM Likelihoods with L2RA Estimates
  - Preliminary Results to Date

# Need for CNA Existing Conditions Assessment

- **Deferred Level 2 RA Schedule no longer meets CNA Schedule needs – CNA Task Teams need to understand higher risks sooner in order to identify risk reduction opportunities and potential risk reduction measures**

# Update on Level 2 Risk Analysis

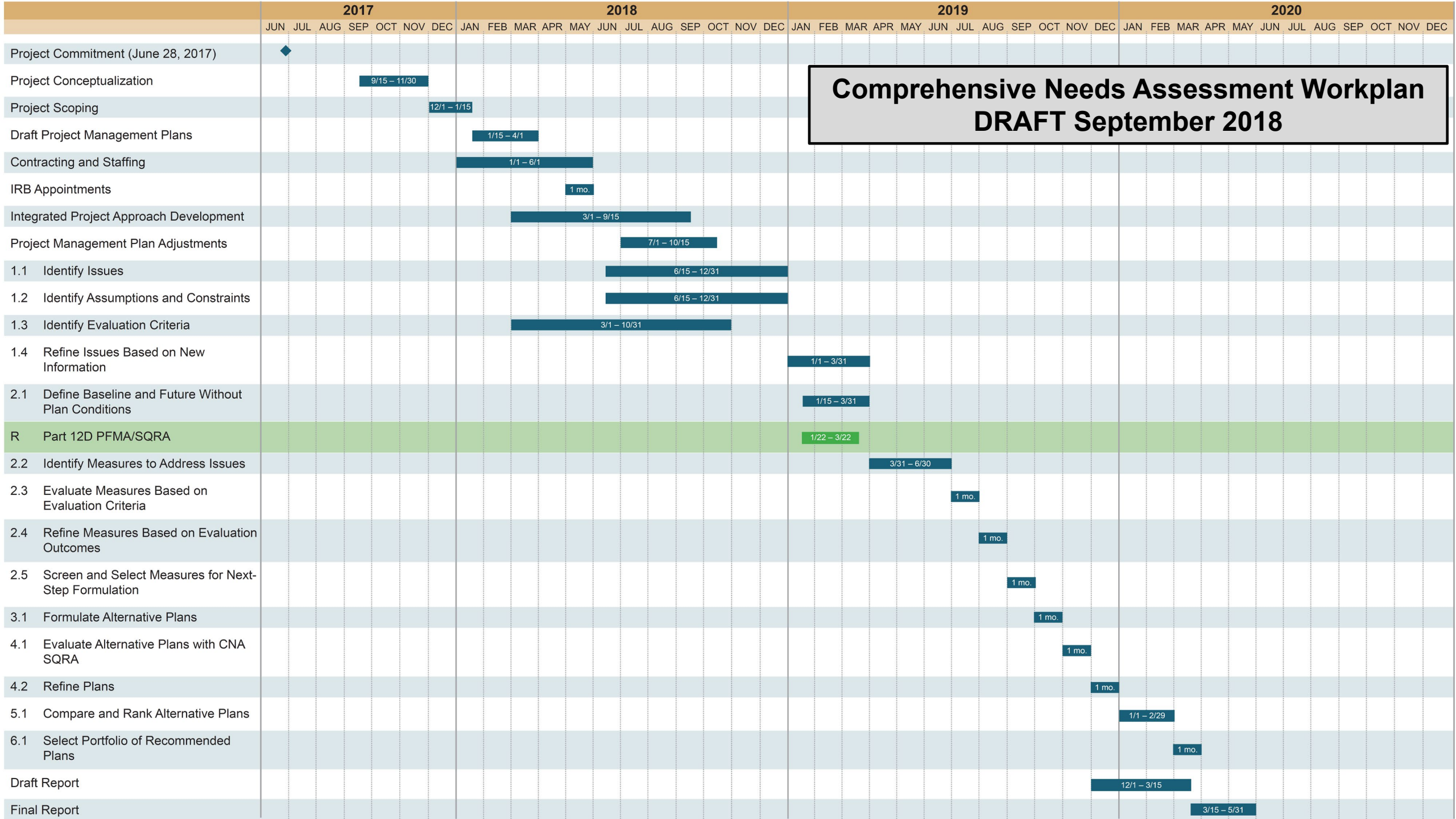
## Original Schedule

| Dates | Workshop Subject Matter |
|---|---|
| January 22 – 25 | Parish Camp, Bidwell Bar Canyon, Main Embankment |
| January 28 – February 1 | Main Embankment |
| February 27 – March 7 | Hyatt Intake, FCO Headworks, Hyatt PP, Palermo Tunnel, and RVOS |
| March 18 – 22 | Post-Construction FCO Chute and Emergency Spillway |

## Revised Schedule

| Dates | Workshop Subject Matter |
|---|---|
| January 22 – 25 | Parish Camp, Bidwell Bar Canyon, Main Embankment |
| January 28 – February 1 | Main Embankment |
| February 27 – March 7 | Hyatt Intake, FCO Headworks, Hyatt PP, Palermo Tunnel, and RVOS |
| March 18 – 22 | Embankments – Week 3 |
| May 8 – 10 | Structural – Week 3 |
| June 24 - 28 | Systems and Human Factors |
| July 8 - 12 | Non-Life Loss |
| July 29 – August 2 | Spillways |

# Comprehensive Needs Assessment Workplan
# DRAFT September 2018



# Need for CNA Existing Conditions Assessment

- Deferred Level 2 RA Schedule no longer meets CNA Schedule needs – CNA Task Teams need to understand higher risks sooner in order to identify risk reduction opportunities and potential risk reduction measures

- **Level 2 RA is largely focused on Ultimate Failure conditions for each PFM with an uncontrolled release of the reservoir – e.g. dam breach or loss of FCO Headworks structure – CNA ECA looks at multiple condition states for each PFM**

# Need for CNA Existing Conditions Assessment

- Deferred Level 2 RA Schedule no longer meets CNA Schedule needs – CNA Task Teams need to understand higher risks sooner in order to identify risk reduction opportunities and potential risk reduction measures
- Level 2 RA is largely focused on Ultimate Failure conditions for each PFM with an uncontrolled release of the reservoir – e.g. dam breach or loss of FCO Headworks structure – CNA ECA looks at multiple condition states for each PFM
- **Level 2 RA largely focused on Life Loss, whereas CNA ECA focuses on 5 criteria of DWR Asset Management Risk Matrix**

# Need for CNA Existing Conditions Assessment

- Deferred Level 2 RA Schedule no longer meets CNA Schedule needs – CNA Task Teams need to understand higher risks sooner in order to identify risk reduction opportunities and potential risk reduction measures
- Level 2 RA is largely focused on Ultimate Failure conditions for each PFM with an uncontrolled release of the reservoir – e.g. dam breach or loss of FCO Headworks structure – CNA ECA looks at multiple condition states for each PFM
- Level 2 RA largely focused on Life Loss, whereas CNA ECA focuses on 5 criteria of DWR Asset Management Risk Matrix
- **Level 2 RA will not consider risk reduction opportunities or risk reduction measures – CNA will – so having the same risk estimators will help ensure consistency**

# How CNA Existing Conditions Assessment Benefits from Level 2 Risk Assessment

- ✓ **CNA ECA is intended as a *Preliminary* Assessment of Existing Conditions to avoid further delays in CNA Project Schedule**
- ✓ **Will make use of available Level 2 RA results and products**
- ✓ **Will utilize additional Level 2 RA results as they become available and circle back to Level 2 RA results when completed**
- ✓ **At the end of both processes, results are expected to be consistent with each other, particularly on PFMs and Life Loss Consequences**

# Update on CNA PFM Development and CNA Existing Conditions Assessment

## Presentation Outline

- **Background**
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  - Risk-Informed Decision Making Approach
  - Ongoing Independent Level 2 Risk Analysis
  - Need for CNA Existing Conditions Assessment
- **Overview of CNA Existing Conditions Assessment**
  - PFM Development and Evaluation
  - Examples of PFM Development
  - Comparisons of Estimated PFM Likelihoods with L2RA Estimates
  - Preliminary Results to Date

# CNA Existing Conditions Assessment

## CNA Plan Formulation Principles

**The CNA Plan Formulation Principles derived directly from DWR Asset Management Matrix**

**DWR Division of Operations and Maintenance Risk Matrix**

| Likelihood | | DWR Division of Operations & Maintenance Risk Matrix | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Likely to occur 10 times a year | 7 | 7 | 14 | 21 | 28 | 35 | 42 | 49 |
| Likely to occur within 1 year | 6 | 6 | 12 | 18 | 24 | 30 | 36 | 42 |
| Likely to occur within 3 years | 5.5 | 5.5 | 11 | 16.5 | 22 | 27.5 | 35 | 38.5 |
| Likely to occur within 10 years | 5 | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
| Likely to occur within 30 years | 4.5 | 4.5 | 9 | 13.5 | 18 | 22.5 | 26 | 31.5 |
| Likely to occur within 100 years | 4 | 4 | 8 | 12 | 16 | 20 | 24 | 28 |
| Likely to occur within 1000 years | 3 | 3 | 6 | 9 | 12 | 15 | 18 | 21 |
| Likely to occur within 10,000 years | 2 | 2 | 4 | 6 | 8 | 10 | 12 | 14 |
| Likely to occur within 100,000 years | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| | Consequence | | | | | | |
|---|---|---|---|---|---|---|---|
| Consequence Category | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic |
| Public Safety | No injury<br>No damage to public or private property | Near miss<br>Or minor property damage | Minor injuries not requiring medical attention<br>Or moderate property damage | Single injury requiring medical attention<br>Or moderate property damage over large area | Multiple injuries or permanent disability<br>Or major property damage | Fatality<br>Or major property damage over large area | Multiple Fatalities |
| Personnel Safety | No injury | Near miss or minor injuries not requiring medical attention | Single injury requiring medical attention | Multiple injuries requiring medical attention or permanent disability | Fatality | Multiple Fatalities | |
| Compliance* | No violation | Minor restrictions or increased oversight. | Violation and fines | Violation(s), fines, restricted use and prosecution | Sanctions. Lose rights to operate a facility | | |
| Flexibility and Reliability – Water Delivery* | No impact | Unable to meet delivery schedule in a Field Division | Unable to meet water delivery schedules in multiple Field Divisions | Inability to meet Table A Allocation<br>Cascading effect results in damage to other facilities | Inability to meet life and safety flows<br>Cascading effect results in uncontrolled release of water | | |
| Flexibility and Reliability – Other SWP Purposes* | No impact | Minor impact to recreation and fish & wildlife | Minor impact to power generation<br>Major impact to recreation and fish & wildlife | Minor impact to flood control<br>Major impact to power generation | Major impact to flood control | | |
| Reputation* | Questions raised by elected local officials | Questions by State or Federal officials | Local media coverage<br>Correspondence from State or Federal officials | State media coverage<br>Legislative hearing | National media coverage<br>Legislative action | Consent to operate SWP revoked | |
| Financial Impact* | < $100k | $100k - $1M | $1M - $10M | $10M - $100M | $100M - $1B | $1B - $10B | > $10B |

*Additional criteria are provided in the Consequence Sub-criteria tables.

| | Consequence | | | | | | |
|---|---|---|---|---|---|---|---|
| Consequence Category | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic |
| Public Safety | No injury<br>No damage to public or private | Near miss<br>Or minor property dama | Minor injuries not requiring medical attention | Single injury requiring medical attention<br>Or major property damage over large area | Multiple injuries or permanent disability<br>rty | Fatality<br>Or major property damage over large area | Multiple Fatalities |
| Personnel Safety | No injury | Near miss or minor injuries not requiring medical attention | Single injury requiring medical attention | requiring medical attention or permanent disability | Fatality | Multiple Fatalities | |
| Compliance* | | Minor res<br>r incre<br>overs | | | | | |
| Flexibility and Reliability – Water Delivery* | | Unable t<br>ivery s<br>a Field | | Inability to meet | Inability to meet | | |
| Flexibility and Reliability – Other SWP Purposes* | | Minor im<br>creati<br>fish & | | | release of water | | |
| ~~Reputation*~~ | Questions raised by elected local officials | Questions by State or Federal officials | Local media coverage<br>Correspondence from State or Federal officials | State media coverage<br>Legislative hearing | National media coverage<br>Legislative action | Consent to operate SWP revoked | |
| Financial Impact* | | $100k | | | | B - $10B | > $10B |

Maximize Public Safety

Maximize Regulatory Compliance

Maximize Flexibility and Reliability for Water Delivery

Maximize Flexibility and Reliability for Other State Water Project Purposes

Minimize Financial Impacts

# Level 2 Risk Analysis Approach

## DWR Division of Operations and Maintenance Risk Matrix

| Likelihood | | DWR Division of Operations & Maintenance Risk Matrix | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Likely to occur 10 times a year | 7 | 7 | 14 | 21 | 28 | 35 | 42 | 49 |
| Likely to occur within 1 year | 6 | 6 | 12 | 18 | 24 | 30 | 36 | 42 |
| Likely to occur within 3 years | 5.5 | 5.5 | 11 | 16.5 | 22 | 27.5 | 35 | 38.5 |
| Likely to occur within 10 years | 5 | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
| Likely to occur within 30 years | 4.5 | 4.5 | 9 | 13.5 | 18 | 22.5 | 26 | 31.5 |
| Likely to occur within 100 years | 4 | 4 | 8 | 12 | 16 | | | |
| Likely to occur within 1000 years | 3 | 3 | 6 | 9 | 12 | | | |
| Likely to occur within 10,000 years | 2 | 2 | 4 | 6 | 8 | | | |
| Likely to occur within 100,000 years | 1 | 1 | 2 | 3 | 4 | | | |
| | | Consequence | | | | | | |
| Consequence Category | | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | | | |

## L2RA Risk Matrix

**Oroville Level 2 Risk Analysis Matrix**

| Failure Likelihood Category | | | | | | | |
|---|---|---|---|---|---|---|---|
| Very High | | | | | | | $10^{-3}$ - $10^{-2}$ |
| High | | | | | | | $10^{-4}$ - $10^{-3}$ |
| Moderate | | | | | | | $10^{-5}$ - $10^{-4}$ |
| Low | | | | | | | $10^{-6}$ - $10^{-5}$ |
| Very Low | | | | | | | $10^{-7}$ - $10^{-6}$ |
| Remote | | | | | | | $< 10^{-7}$ |
| | DWR AM Category 6 | DWR AM Category 7 | | | | | |
| | FERC Level 1 | FERC Level 2 | FERC Level 3 | FERC Level 4 | FERC Level 5 | | |
| | 0-1 | 1-10 | 10-100 | 100-1000 | 1,000 - 10,000 | > 10,000 | |

Incremental Life Loss Consequence Category

## Merging:

**DWR Asset Management Risk Matrix**
**with**
**FERC Level 2 Risk Matrix**

# Comprehensive Needs Assessment – Extension of DWR Asset Management Risk Matrix

| Likelihood Annual Probability | | Comprehensive Needs Assessment – Extension of DWR Division of Operations & Maintenance Risk Matrix | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic | 8 | 9 | 10 | 11 |
| 1 | 10 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1 | 9 | 9 | 18 | 27 | 36 | 45 | 54 | 63 | 72 | 81 | 90 | 99 |
| $3 \times 10^{-1} - 1$ | 8.5 | 8.5 | 17 | 25.5 | 34 | 42.5 | 51 | 59.5 | 68 | 76.5 | 85 | 93.5 |
| $10^{-1} - 3 \times 10^{-1}$ | 8 | 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 | 72 | 80 | 88 |
| $3 \times 10^{-2} - 10^{-1}$ | 7.5 | 7.5 | 15 | 22.5 | 30 | 37.5 | 45 | 52.5 | 60 | 67.5 | 75 | 82.5 |
| $10^{-2} - 3 \times 10^{-2}$ | 7 | 7 | 14 | 21 | 28 | 35 | 42 | 49 | 56 | 63 | 70 | 77 |
| $10^{-3} - 10^{-2}$ | 6 | 6 | 12 | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 | 66 |
| $10^{-4} - 10^{-3}$ | 5 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| $10^{-5} - 10^{-4}$ | 4 | 4 | 8 | 12 | 16 | 20 | 24 | 28 | 32 | 36 | 40 | 44 |
| $10^{-6} - 10^{-5}$ | 3 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 |
| $10^{-7} - 10^{-6}$ | 2 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| $< 10^{-7}$ | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| **Consequence Category** | | **Consequence** | | | | | | | | | | |
| | | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic | 8 | 9 | 10 | 11 |
| **Public Safety (including Personnel Safety)** | | No injury | Near miss, minor injuries | Minor injuries | Single injury | Multiple injuries, permanent disability | Fatality<br>0 – 1 fatalities | Multiple Fatalities 1 -10 fatalities | 10 – 100 fatalities | 100 – 1,000 fatalities | 1,000 – 10,000 fatalities | > 10,000 fatalities |
| **Financial Impacts (Direct and Indirect)** | | < $100k | $100k - $1M | $1M - $10M | $10M- $100M | $100M - $1B | $1B - $10B | $10B - $100B | $100B - $250B | $250B - $500B | $500B - $1T | > $1T |

# Comprehensive Needs Assessment – Extension of DWR Asset Management Risk Matrix

| Likelihood Annual Probability | | Comprehensive Needs Assessment – Extension of DWR Division of Operations & Maintenance Risk Matrix | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic | 8 | 9 | 10 | 11 |
| 1 | 10 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1 | 9 | 9 | 18 | 27 | 36 | 45 | 54 | 63 | 72 | 81 | 90 | 99 |
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| $10^{-1} - 3 \times 10^{-1}$ | 8 | 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 | 72 | 80 | 88 |
| $3 \times 10^{-2} - 10^{-1}$ | 7.5 | 7.5 | 15 | 22.5 | 30 | 37.5 | 45 | 52.5 | 60 | 67.5 | 75 | 82.5 |
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| $10^{-7} - 10^{-6}$ | 2 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| $< 10^{-7}$ | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |

Original DWR AM Risk Matrix

| Consequence Category | Consequence | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic | 8 | 9 | 10 | 11 |
| **Public Safety (including Personnel Safety)** | No injury | Near miss, minor injuries | Minor injuries | Single injury | Multiple injuries, permanent disability | Fatality<br>0 – 1 fatalities | Multiple Fatalities 1 -10 fatalities | 10 – 100 fatalities | 100 – 1,000 fatalities | 1,000 – 10,000 fatalities | > 10,000 fatalities |
| **Financial Impacts (Direct and Indirect)** | < $100k | $100k - $1M | $1M - $10M | $10M- $100M | $100M - $1B | $1B - $10B | $10B - $100B | $100B - $250B | $250B - $500B | $500B - $1T | > $1T |

# Comprehensive Needs Assessment – Extension of DWR Asset Management Risk Matrix

| Likelihood Annual Probability | | Comprehensive Needs Assessment – Extension of DWR Division of Operations & Maintenance Risk Matrix | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic | 8 | 9 | 10 | 11 |
| 1 | 10 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1 | 9 | 9 | 18 | 27 | 36 | 45 | 54 | 63 | 72 | 81 | 90 | 99 |
| $3 \times 10^{-1} - 1$ | 8.5 | 8.5 | 17 | 25.5 | 34 | 42.5 | 51 | 59.5 | 68 | 76.5 | 85 | 93.5 |
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| $10^{-2} - 3 \times 10^{-2}$ | 7 | 7 | 14 | 21 | 28 | 35 | 42 | 49 | | | 70 | 77 |
| $10^{-3} - 10^{-2}$ | 6 | 6 | 12 | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 | 66 |
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| $10^{-6} - 10^{-5}$ | 3 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 |
| $10^{-7} - 10^{-6}$ | 2 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| $< 10^{-7}$ | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |

L2RA Risk Matrix

| Consequence Category | Consequence | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic | 8 | 9 | 10 | 11 |
| **Public Safety (including Personnel Safety)** | No injury | Near miss, minor injuries | Minor injuries | Single injury | Multiple injuries, permanent disability | Fatality<br>0 – 1 fatalities | Multiple Fatalities 1 -10 fatalities | 10 – 100 fatalities | 100 – 1,000 fatalities | 1,000 – 10,000 fatalities | > 10,000 fatalities |
| **Financial Impacts (Direct and Indirect)** | < $100k | $100k - $1M | $1M - $10M | $10M- $100M | $100M - $1B | $1B - $10B | $10B - $100B | $100B - $250B | $250B - $500B | $500B - $1T | > $1T |

# Comprehensive Needs Assessment – Extension of DWR Asset Management Risk Matrix

| Likelihood Annual Probability | | Comprehensive Needs Assessment – Extension of DWR Division of Operations & Maintenance Risk Matrix | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic | 8 | 9 | 10 | 11 |
| 1 | 10 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| 1 | 9 | 9 | 18 | 27 | 36 | 45 | 54 | 63 | 72 | 81 | 90 | 99 |
| $3 \times 10^{-1} - 1$ | 8.5 | 8.5 | 17 | 25.5 | 34 | 42.5 | 51 | 59.5 | 68 | 76.5 | 85 | 93.5 |
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| $3 \times 10^{-2} - 10^{-1}$ | 7.5 | 7.5 | 15 | 22.5 | 30 | 37.5 | 45 | 52.5 | 60 | 67.5 | 75 | 82.5 |
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| $10^{-6} - 10^{-5}$ | 3 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 |
| $10^{-7} - 10^{-6}$ | 2 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| $< 10^{-7}$ | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| **Consequence Category** | | **Consequence** | | | | | | | | | | |
| | | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic | 8 | 9 | 10 | 11 |
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| **Financial Impacts (Direct and Indirect)** | | < $100k | $100k - $1M | $1M - $10M | $10M- $100M | $100M - $1B | $1B - $10B | $10B - $100B | $100B - $250B | $250B - $500B | $500B - $1T | > $1T |

**Tolerable Risk Guidelines for Dam Safety from FERC and other Federal Agencies**

# 171 Pre-Workshop PFMs Considered in Previous PFMA Workshops and Brainstorming Ideas Submitted by Level 2 Workshop Participants

| PFM No. | No. | Dam | PFM Description | Loading | Component | Mechanism | CNA Task Team | PFM Group (A, B, C, D) | Previous Category | Submitter |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | Oroville Dam | CBND: foundation material | | | | 5 | | | |
| 2 | | Oroville Dam | CBND: grout curtain foundation | | | | 5 | | | |
| 3 | | Oroville Dam | CBND: | | | | 5 | | | |
| 4 | | Oroville Dam | CBND: earthqu | | | | 5 | | | |
| 5 | | Oroville Dam | CBND: shears in the dam foundation during seismic event. | | | Stability | 5 | | | |
| 6 | | Oroville Dam | CBND: Seismic damage to site access roads and bridges | Earthquake | Embankment | Dam Access | 5 | | | |
| 7 | | Orovi | | | | | | | | |
| 8 | | Orovi | | | | | | | | P. Risher |
| 9 | | Orovi | | | | | | | | C. Womack |
| 10 | H-3 | Orovi | | | | | | | 2 | |
| 11 | | Orovi | overtopping of Oroville Dam. | | | | | | | |
| 12 | | Or | Internal erosion of fines from seepage barrier exiting into | | | Internal | | | | D. Panec |
| 13 | | Or | | | | | | | | T. Hepler |
| 14 | | Or | | | | | | | | C. Womack |

- ✓ 35 PFMs (1 - 35) for Embankments
- ✓ 19 PFMs (36 – 52, 116, 117) Emergency Spillway
- ✓ 64 PFMs (53 – 115, 118) for FCO
- ✓ 53 PFMs (119 – 171) for Hyatt, Palermo, and RVOS outlets
- ✓ 171 PFMs Total

- *Some PFMs – Previously Considered But Not Developed (CBND)*
- *Additional PFMs added during Level 2 Risk Analysis Workshop Sessions*

# CNA Existing Conditions Assessment
# PFM Development

## ➢ Potential Failure Mode Analyses (PFMA):

### ✓ Consideration and Development of PFMs – Example: Progression of Internal Erosion PFM

Reservoir at or above threshold level
Initiation – Erosion starts
Continuation – Unfiltered or inadequately filtered exit exists
Progression – Continuous stable roof and/or sidewalls
Progression – Constriction or upstream zone fails to limit flows
Progression – No self-healing by upstream zone
Unsuccessful detection and intervention
Dam breaches (uncontrolled release of reservoir)

**from "*Best Practices in Dam and Levee Safety Risk Analysis*," United States Bureau of Reclamation and Army Corps of Engineers**

# Potential Failure Modes

- Key Points to remember about PFMs and PFMAs
  - To the FERC, a failure is an **uncontrolled release** of water.
  - Operation of an emergency spillway is not an uncontrolled release of water.
  - Is such a thing as a restricted uncontrolled release – outlet works, turbine, etc… Still considered a failure.

- Licensee Concerns
  - **Unacceptable performance** could be a failure to Licensee
  - A Licensee may consider the loss of a turbine a PFM even without a release of water. The FERC is concerned but it is not a dam safety concern

Example - Wanapum Dam



**Past Focus on only *"Uncontrolled Release of Water"***

**from FERC Part 12D Training Workshop, January 2015**

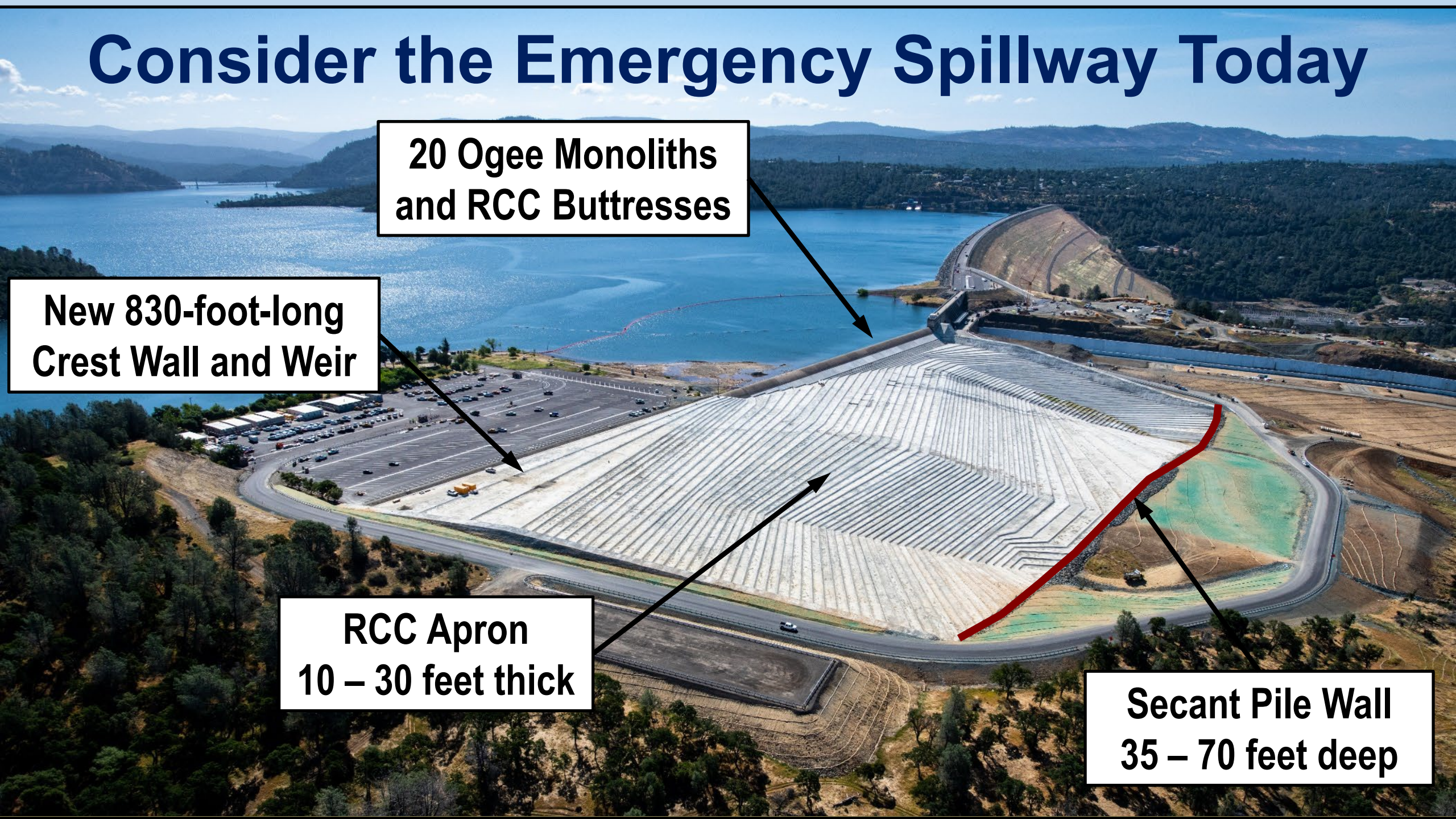
# Independent Forensic Team - Lessons Learned

**In practice today, PFMAs appear to be limited mainly to consideration of potential failures modes that lead to uncontrolled release of the reservoir. This can lead to potential failure modes with significant consequences short of reservoir release being ruled out of further consideration. In the case of Oroville Dam, the 2014 PFMA team essentially identified the two failures modes which initiated in February 2017, but ruled them out in large part because they were judged to be unlikely to lead to release of stored reservoir water….**

**…By ruling out these failure modes, they may have been removed from any further consideration in subsequent studies including future PFMAs.**

from Independent Forensic Team Final Report, Pages 78-79, January 2018

# Consider the Emergency Spillway Today



# Consider the Emergency Spillway Today

**PFM T1-6.1a:**

***Ultimate Failure State*:**

**Failure of Secant Pile Wall, RCC Apron, and the 6 Large Monoliths – Leading to Uncontrolled Release, Significant Incremental Downstream Damages**

# Consider the Emergency Spillway Today

**PFM T1-6.1a:**

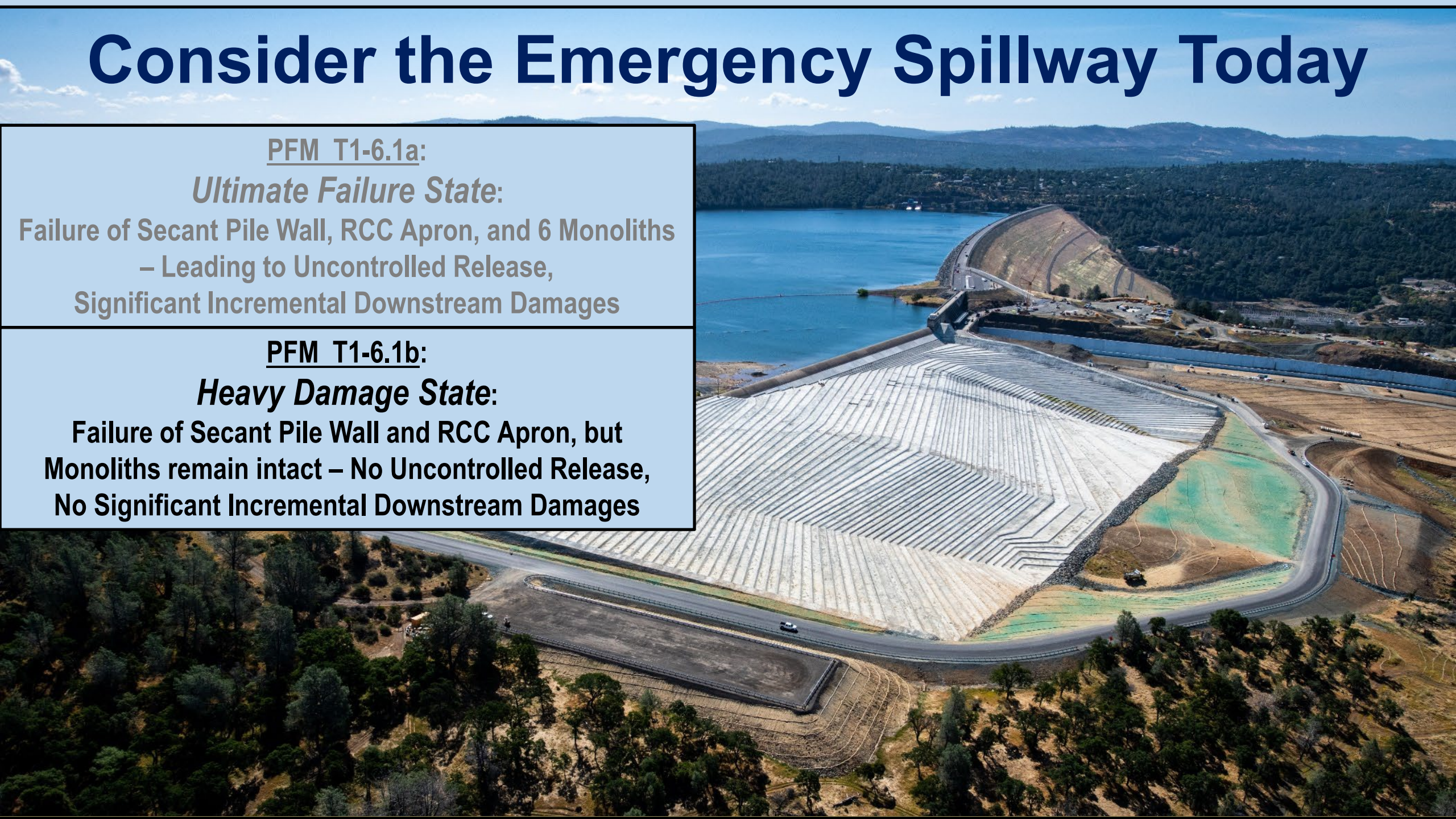
***Ultimate Failure State*:**

**Failure of Secant Pile Wall, RCC Apron, and 6 Monoliths – Leading to Uncontrolled Release, Significant Incremental Downstream Damages**

**PFM T1-6.1b:**

***Heavy Damage State*:**

**Failure of Secant Pile Wall and RCC Apron, but Monoliths remain intact – No Uncontrolled Release, No Significant Incremental Downstream Damages**



# Consider the Emergency Spillway Today

**PFM T1-6.1a:**

***Ultimate Failure State*:**

Failure of Secant Pile Wall, RCC Apron, and 6 Monoliths – Leading to Uncontrolled Release, Significant Incremental Downstream Damages

**PFM T1-6.1b:**

***Heavy Damage State*:**

Failure of Secant Pile Wall and RCC Apron, but Monoliths remain intact – No Uncontrolled Release, No Significant Incremental Downstream Damages

**PFM T1-6.1c:**

***Light Damage State*:**

**Very Localized Failure of Secant Pile Wall and Damage to RCC Apron, but Monoliths remain intact – No Uncontrolled Release, No Significant Incremental Downstream Damages**

# T1-6 Risk Summary – Public Safety and Life Loss

| PFM No. | PFM Description |
|---|---|
| T1-6 | PMF and 100k cfs loading, erosion rock d/s of secant pile wall, headward cutting/erosion through secant pile wall and RCC apron. Erosion destabilizes ES monoliths 15-20. |

Preliminary

**Risk Matrix: Public Safety & Life Loss**

| Total likelihood of failure | 1□ Insignificant | 2□ Minor | 3□ Moderate | 4□ High | 5□ Major | 6□ Extreme, Life loss 0-1 | 7□ Catastrophic, Life loss 1-10 | 8□ Life loss 10-100 | 9□ Life loss 100-1,000 | 10□ Life loss 1,000-10,000 | 11□ Life loss > 10,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Likely to occur 10 times a year | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| Likely to occur within 1 year | 9 | 18 | 27 | 36 | 45 | 54 | 63 | 72 | 81 | 90 | 99 |
| Likely to occur within 3 years | 8.5 | 17 | 25.5 | 34 | 42.5 | 51 | 59.5 | 68 | 76.5 | 85 | 93.5 |
| Likely to occur within 10 years | 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 | 72 | 80 | 88 |
| Likely to occur within 30 years | 7.5 | 15 | 22.5 | 30 | 37.5 | 45 | 52.5 | 60 | 67.5 | 75 | 82.5 |
| Likely to occur within 100 years | 7 | 14 | 21 | 28 | 35 | 42 | 49 | 56 | 63 | 70 | 77 |
| Likely to occur within 1,000 years | **6** | 12 | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 | 66 |
| Likely to occur within 10,000 years | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| Likely to occur within 100,000 years | **4** | 8 | 12 | 16 | 20 | 24 | 28 | 32 | 36 | 40 | 44 |
| Likely to occur within 1,000,000 years | 3 | **T1-6.3** | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 |
| Likely to occur within 10,000,000 years | **2** | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| Likely to occur less often than 10,000,000 years | 1 | **T1-6.1c&2c** | 3 | 4 | 5 | 6 | 7 | 8 | **9** | 10 | 11 |

# T1-6 Risk Summary – Regulatory Compliance

| PFM No. | PFM Description |
|---|---|
| T1-6 | PMF and 100k cfs loading, erosion rock d/s of secant pile wall, headward cutting/erosion through secant pile wall and RCC apron. Erosion destabilizes ES monoliths 15-20. |

Preliminary

**Risk Matrix: Compliance**

| Total likelihood of failure | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major |
|---|---|---|---|---|---|
| Likely to occur 10 times a year | 10 | 20 | 30 | 40 | 50 |
| Likely to occur within 1 year | 9 | 18 | 27 | 36 | 45 |
| Likely to occur within 3 years | 8.5 | 17 | 25.5 | 34 | 42.5 |
| Likely to occur within 10 years | 8 | 16 | 24 | 32 | 40 |
| Likely to occur within 30 years | 7.5 | 15 | 22.5 | 30 | 37.5 |
| Likely to occur within 100 years | 7 | 14 | 21 | 28 | 35 |
| Likely to occur within 1,000 years | **6** | **T1-6.3** | 18 | 24 | 30 |
| Likely to occur within 10,000 years | 5 | 10 | 15 | 20 | 25 |
| Likely to occur within 100,000 years | 4 | 8 | **12** | **T1-6.1c&2c** | 20 |
| Likely to occur within 1,000,000 years | 3 | 6 | 9 | 12 | 15 |
| Likely to occur within 10,000,000 years | 2 | 4 | **6** | **T1-6.1b&2b** | 10 |
| Likely to occur less often than 10,000,000 years | 1 | 2 | 3 | **4** | **5** |
| | | | | **T1-6.2a** | **T1-6.1a** |

# T1-6 Risk Summary – SWP Water Delivery

| PFM No. | PFM Description |
|---|---|
| T1-6 | PMF and 100k cfs loading, erosion rock d/s of secant pile wall, headward cutting/erosion through secant pile wall and RCC apron. Erosion destabilizes ES monoliths 15-20. |

Preliminary

**Risk Matrix: Compliance**

Preliminary

**Risk Matrix: Flexibility and Reliability - Water Delivery**

| Total likelihood of failure | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major |
|---|---|---|---|---|---|
| Likely to occur 10 times a year | 10 | 20 | 30 | 40 | 50 |
| Likely to occur within 1 year | 9 | 18 | 27 | 36 | 45 |
| Likely to occur within 3 years | 8.5 | 17 | 25.5 | 34 | 42.5 |
| Likely to occur within 10 years | 8 | 16 | 24 | 32 | 40 |
| Likely to occur within 30 years | 7.5 | 15 | 22.5 | 30 | 37.5 |
| Likely to occur within 100 years | 7 | 14 | 21 | 28 | 35 |
| Likely to occur within 1,000 years | **6** | **T1-6.3** | 18 | 24 | 30 |
| Likely to occur within 10,000 years | 5 | 10 | 15 | 20 | 25 |
| Likely to occur within 100,000 years | 4 | 8 | **12** | **T1-6.1c&2c** | 20 |
| Likely to occur within 1,000,000 years | 3 | 6 | 9 | 12 | 15 |
| Likely to occur within 10,000,000 years | 2 | 4 | **6** | **T1-6.1b&2b** | 10 |
| Likely to occur less often than 10,000,000 years | 1 | 2 | 3 | 4 | **5** **T1-6.1a&2a** |

# T1-6 Risk Summary – Other SWP Purposes

| PFM No. | PFM Description |
|---|---|
| T1-6 | PMF and 100k cfs loading, erosion rock d/s of secant pile wall, headward cutting/erosion through secant pile wall and RCC apron. Erosion destabilizes ES monoliths 15-20. |

Preliminary

**Risk Matrix: Compliance**

Preliminary

**Risk Matrix: Flexibility and Reliability - Water Delivery**

Preliminary

**Risk Matrix: Flexibility and Reliability - Other SWP Purposes**

| Total likelihood of failure | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major |
|---|---|---|---|---|---|
| Likely to occur 10 times a year | 10 | 20 | 30 | 40 | 50 |
| Likely to occur within 1 year | 9 | 18 | 27 | 36 | 45 |
| Likely to occur within 3 years | 8.5 | 17 | 25.5 | 34 | 42.5 |
| Likely to occur within 10 years | 8 | 16 | 24 | 32 | 40 |
| Likely to occur within 30 years | 7.5 | 15 | 22.5 | 30 | 37.5 |
| Likely to occur within 100 years | 7 | 14 | 21 | 28 | 35 |
| Likely to occur within 1,000 years | **6** | **T1-6.3** | 18 | 24 | 30 |
| Likely to occur within 10,000 years | 5 | 10 | 15 | 20 | 25 |
| Likely to occur within 100,000 years | 4 | **8** | **T1-6.1c&2c** | 16 | 20 |
| Likely to occur within 1,000,000 years | 3 | 6 | 9 | 12 | 15 |
| Likely to occur within 10,000,000 years | 2 | 4 | **6** | **T1-6.1b&2b** | 10 |
| Likely to occur less often than 10,000,000 years | 1 | 2 | **T1-6.3** | 4 | **5** **T1-6.1a&2a** |

# T1-6 Risk Summary – Financial Impact

| PFM No. | PFM Description |
|---|---|
| T1-6 | PMF and 100k cfs loading, erosion rock d/s of secant pile wall, headward cutting/erosion through secant pile wall and RCC apron. Erosion destabilizes ES monoliths 15-20. |

Preliminary

**Risk Matrix: Compliance**

Preliminary

**Risk Matrix: Flexibility and Reliability - Water Delivery**

Preliminary

**Risk Matrix: Flexibility and Reliability - Other SWP Purposes**

Preliminary

**Risk Matrix: Financial Impact**

| Total likelihood of failure | 1□ Insignificant | 2□ Minor | 3□ Moderate | 4□ High | 5□ Major | 6□ Extreme | 7□ Catastrophic | 8□ $100B - $250B | 9□ $250B - $500B | 10□ $500B - $1T | 11□ > $1T |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Likely to occur 10 times a year | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| Likely to occur within 1 year | 9 | 18 | 27 | 36 | 45 | 54 | 63 | 72 | 81 | 90 | 99 |
| Likely to occur within 3 years | 8.5 | 17 | 25.5 | 34 | 42.5 | 51 | 59.5 | 68 | 76.5 | 85 | 93.5 |
| Likely to occur within 10 years | 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 | 72 | 80 | 88 |
| Likely to occur within 30 years | 7.5 | 15 | 22.5 | 30 | 37.5 | 45 | 52.5 | 60 | 67.5 | 75 | 82.5 |
| Likely to occur within 100 years | 7 | 14 | 21 | 28 | 35 | 42 | 49 | 56 | 63 | 70 | 77 |
| Likely to occur within 1,000 years | **6** | 12 | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 | 66 |
| Likely to occur within 10,000 years | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| Likely to occur within 100,000 years | 4 | 8 | 12 | **16** | 20 | 24 | 28 | 32 | 36 | 40 | 44 |
| Likely to occur within 1,000,000 years | 3 | 6 | **T1-6.3** | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 |
| Likely to occur within 10,000,000 years | 2 | 4 | 6 | **8** | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| Likely to occur less often than 10,000,000 years | 1 | 2 | 3 | 4 | 5 | **6** | 7 | 8 | 9 | 10 | 11 |

| PFM No. | PFM Description | | | | Risk Score by Consequence Category | | | | |
|---|---|---|---|---|---|---|---|---|---|
| T5-16 | Concentrated leak erosion along instrumentation trenches and abandoned instrumentation bundles leads to failure by internal erosion. | | | | | | | | |
| ID | Loading | Failure Description | Total likelihood of failure | | Public Safety & Life Loss | Compliance | Flexibility and Reliability - Water Delivery | Flexibility and Reliability – Other SWP Purposes | Financial Impact |
| 1 | T5-16.1 | Concentrated erosion through a defect in the instrumentation trench leading to seepage and develops continuing erosion into Zone 2 material, Upstream Zones 2 and 3 fail to limit flow and lead to breach. | Likely to occur within 10,000,000 years | 2 | 20 | 10 | 10 | 10 | 16 |
| 2 | T5-16.2 | Concentrated Leak Erosion through a defect in the instrumentation trench leading to excessive erosion along the trench. Upstream Zone 2 and 3 material eventually limit flow and halt upstream progression after erosion of the upstream Zone 3 material resulting in both a surficial depression on the upstream dam face and higher baseline seepage flows in the downstream seepage collection system but no breach. | Likely to occur within 1,000,000 years | 3 | 21 | 12 | 9 | 9 | 18 |
| 3 | T5-16.3 | Concentrated Leak Erosion through a defect in the instrumentation trench leading to excessive erosion along the trench. Upstream Zone 2 and 3 material limit flow and halt upstream progression resulting in higher baseline seepage flows in the downstream seepage collection system but no breach. | Likely to occur within 100,000 years | 4 | 16 | 8 | 8 | 8 | 12 |
| 4 | T5-16.4 | Concentrated seepage through a defect in the instrumentation trench that extends to the midpoint of the core where the instrument tubing turns vertical. The seepage intersects the broken tubing resulting in increased flows in the instrumentation tubing bundles at the terminal T and/or S. | Likely to occur within 10,000 years | 5 | 5 | 5 | 5 | 5 | 10 |

Preliminary

| PFM No. | PFM Description | | | | Risk Score by Consequence Category | | | | |
|---|---|---|---|---|---|---|---|---|---|
| T5-16 | Concentrated leak erosion along instrumentation trenches and abandoned instrumentation bundles leads to failure by internal erosion. | | | | | | | | |
| ID | Loading | Failure Description | Total likelihood of failure | | Public Safety & Life Loss | Compliance | Flexibility and Reliability - Water Delivery | Flexibility and Reliability – Other SWP Purposes | Financial Impact |
| 1 | T5-16.1 | Concentrated erosion through a defect in the instrumentation trench leading to seepage and develops continuing erosion into Zone 2 material, Upstream Zones 2 and 3 fail to limit flow and lead to breach. | Likely to occur within 10,000,000 years | 2 | 20 | 10 | 10 | 10 | 16 |
| 2 | T5-16.2 | Concentrated Leak Erosion through a defect in the instrumentation trench leading to excessive erosion along the trench. Upstream Zone 2 and 3 material eventually limit flow and halt upstream progression after erosion of the upstream Zone 3 material resulting in both a surficial depression on the upstream dam face and higher baseline seepage flows in the downstream seepage collection system but no breach. | Likely to occur within 1,000,000 years | 3 | 21 | 12 | 9 | 9 | 18 |
| 3 | T5-16.3 | Concentrated Leak Erosion through a defect in the instrumentation trench leading to excessive erosion along the trench. Upstream Zone 2 and 3 material limit flow and halt upstream progression resulting in higher baseline seepage flows in the downstream seepage collection system but no breach. | Likely to occur within 100,000 years | 4 | 16 | 8 | 8 | 8 | 12 |
| 4 | T5-16.4 | Concentrated seepage through a defect in the instrumentation trench that extends to the midpoint of the core where the instrument tubing turns vertical. The seepage intersects the broken tubing resulting in increased flows in the instrumentation tubing bundles at the terminal T and/or S. | Likely to occur within 10,000 years | 5 | 5 | 5 | 5 | 5 | 10 |

**Focus of L2RA Evaluations**

**Preliminary**

# CNA Existing Conditions Assessment

## Status

- ✓ Over 372 PFMs Considered
- ✓ ~127 PFMs fully developed (~245 CBND)
- ✓ Generally 3 to 4 Scenarios developed per PFM
  - ➡ ~407 PFM Scenarios fully developed
    (~3+ Scenarios/PFM x 127 PFMs = ~407 Scenarios)
- ✓ 5 Consequence Conditions Assessed per PFM Scenario
  - ➡ ~2056 PFM Consequences fully evaluated
    (~5 Consequences/Scenario x 407 Scenarios = ~2056)

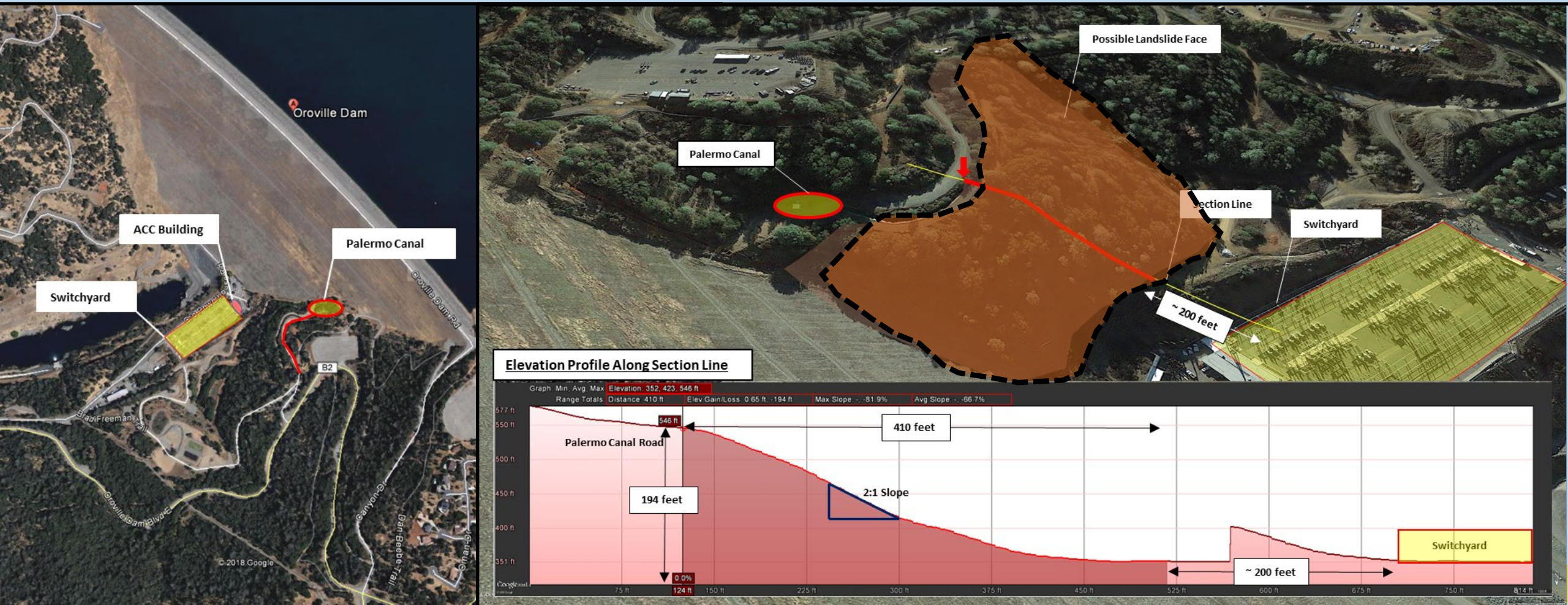
# Update on CNA PFM Development and CNA Existing Conditions Assessment

## Presentation Outline

- **Background**
  - Review:  Purpose of the CNA
  - Risk-Informed Decision Making Approach
  - Ongoing Independent Level 2 Risk Analysis
  - Need for CNA Existing Conditions Assessment
- **Overview of CNA Existing Conditions Assessment**
  - PFM Development and Evaluation
  - **Example of PFM Development**
  - Comparisons of Estimated PFM Likelihoods with L2RA Estimates
  - Preliminary Results to Date

# HPS-3-A.1 – Summary

Major landslide triggered in cut slope below Palermo Canal due to leaks in canal lining, debris buries switchyard and shuts down Hyatt PP



# HPS-3-A– PFM Event Tree

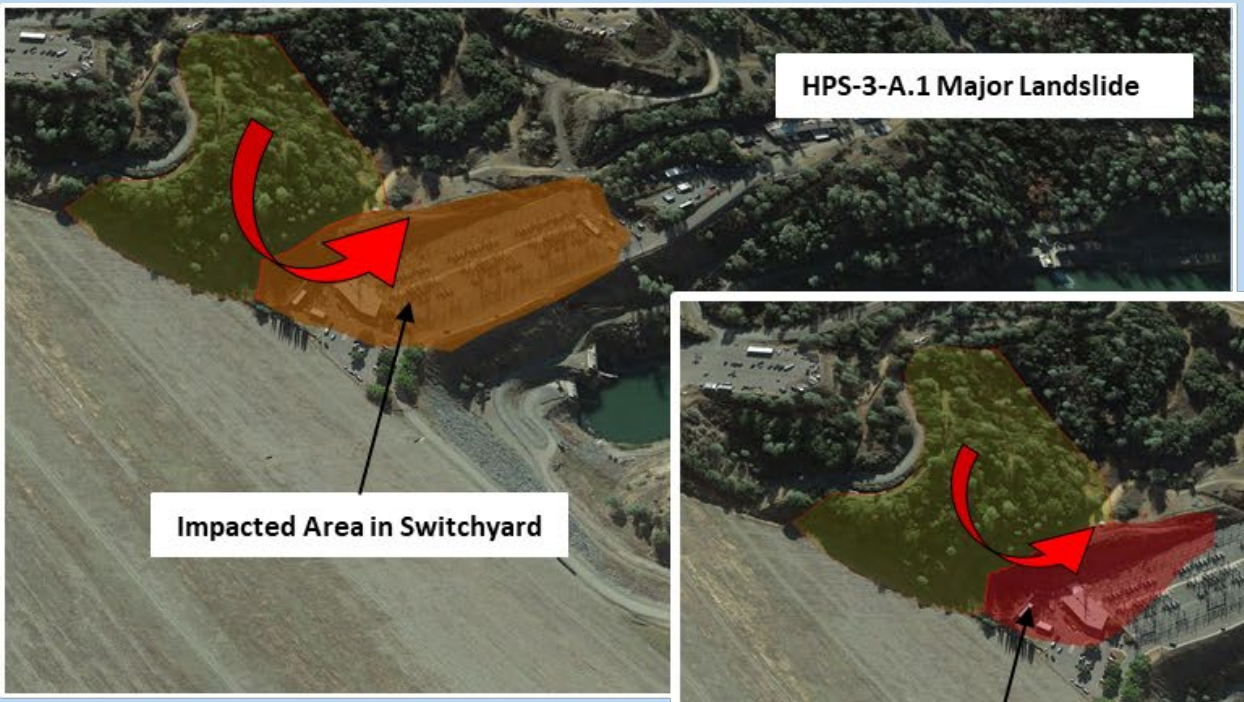
- **HPS-3-A.1**
  - Reservoir is above **El. 640**, all units in Hyatt are generating power
    - Initiation – **Water leaks** from Palermo canal. Slope materials retain water, creating high pore pressure and loss of shear strength.
      - Continuation – **Large landslide** is triggered in cut slopes below Palermo Canal (Figures HPS 3A-A, B).
        - Progression – **Large amount of landslide debris** flows about 200 feet and **completely buries** switchyard.
          - Switchyard is inoperable for **6-12 months** and causes shutdown of Hyatt Powerplant.

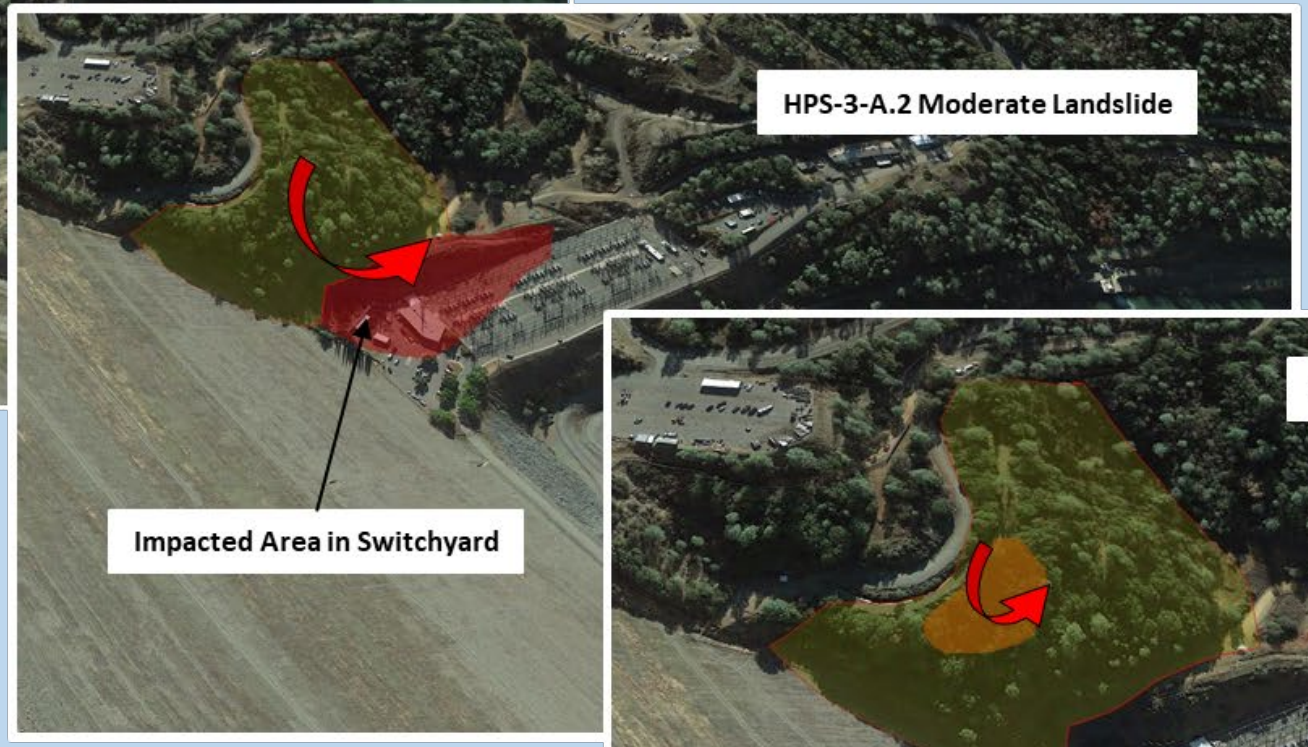
- **HPS-3-A.2**
  - **Moderate landslide** triggered in cut slope below Palermo Canal due to leaks in canal lining-debris **partially buries** and shutdown switchyard for about **4 weeks**.

- **HPS-3-A.3**
  - **Small slump** in in cut slope below Palermo Canal due to **minor leaks** in canal lining- **no impact** on switchyard operations.

- **HPS-3-A.4**
  - **Visible seepage and wet spots** in cut slope below Palermo Canal due to minor leaks in canal lining- **no impact** to switchyard operations.

# HPS-3-A PFM Scenario Visualization




# HPS-3-A– Risk Matrix

| PFM No. | PFM Description |
|---|---|
| HPS-3-A | Normal Event.Loss of Power Generation – Switchyard/Transmission system offline (grid separation) due to Landslide. |

**Risk Matrix: Public Safety & Life Loss**

| Total likelihood of failure | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme, Life loss 0-1 | 7 Catastrophic, Life loss 1-10 | 8 Life loss 10-100 | 9 Life loss 100-1,000 | 10 Life loss 1,000-10,000 | 11 Life loss > 10,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Likely to occur 10 times a year | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| Likely to occur within 1 year | 9 | 18 | 27 | 36 | 45 | 54 | 63 | 72 | 81 | 90 | 99 |
| Likely to occur within 3 years | 8.5 | 17 | 25.5 | 34 | 42.5 | 51 | 59.5 | 68 | 76.5 | 85 | 93.5 |
| Likely to occur within 10 years | 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 | 72 | 80 | 88 |
| Likely to occur within 30 years | 7.5 | 15 | 22.5 | 30 | 37.5 | 45 | 52.5 | 60 | 67.5 | 75 | 82.5 |
| Likely to occur within 100 years | **7** | 14 | 21 | 28 | 35 | 42 | 49 | 56 | 63 | 70 | 77 |
| Likely to occur within 1,000 years | 6 | **12** | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 | 66 |
| Likely to occur within 10,000 years | 5 | 10 | **15** | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| Likely to occur within 100,000 years | 4 | 8 | 12 | 16 | 20 | **24** | 28 | 32 | 36 | 40 | 44 |
| Likely to occur within 1,000,000 years | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 |
| Likely to occur within 10,000,000 years | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| Likely to occur less often than 10,000,000 years | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |

HPS-3A.4

HPS-3A.3

HPS-3A.2

HPS-3A.1

**Risk Matrix: Financial Impact**

| Total likelihood of failure | 1 Insignificant | 2 Minor | 3 Moderate | 4 High | 5 Major | 6 Extreme | 7 Catastrophic | 8 $100B - $250B | 9 $250B - $500B | 10 $500B - $1T | 11 > $1T |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Likely to occur 10 times a year | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
| Likely to occur within 1 year | 9 | 18 | 27 | 36 | 45 | 54 | 63 | 72 | 81 | 90 | 99 |
| Likely to occur within 3 years | 8.5 | 17 | 25.5 | 34 | 42.5 | 51 | 59.5 | 68 | 76.5 | 85 | 93.5 |
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| Likely to occur within 10,000 years | 5 | 10 | **15** | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| Likely to occur within 100,000 years | 4 | 8 | 12 | 16 | **20** | 24 | 28 | 32 | 36 | 40 | 44 |
| Likely to occur within 1,000,000 years | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 |
| Likely to occur within 10,000,000 years | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
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- **Overview of CNA Existing Conditions Assessment**
  - PFM Development and Evaluation
  - Example of PFM Development
  - Comparisons of Estimated PFM Likelihoods with L2RA Estimates
  - Preliminary Results to Date

# Comparison of CNA and L2RA PFMs Developed

Preliminary

| CNA Task Team | | | | Level 2 Risk Analysis | | PFMs Able to be Compared |
|---|---|---|---|---|---|---|
| Task Teams | Facility | No. of PFMs Considered | No. of PFMs Developed | No. of PFMs Considered | No. of PFMs Developed | |
| Task 1: Emergency Spillway | Monoliths, Apron, SPW, Hillside | 34 | 9 [9] | | | |
| Task 3: FCO | Headworks | 89 | 31 [37] | | | |
| | Chute | | 6 | | | |
| Task 4: Low Level Outlets | HPP Intake | 86 | 9 | | | |
| | HPP and Switchyard | | 8 [31] | | | |
| | RVOS | | 8 | | | |
| | Palermo | | 6 | | | |
| Task 5: Embankments | Main Dam | 163 | 30 | | | |
| | Bidwell Bar Cyn SD | | 11 [50] | | | |
| | Parish Camp SD | | 9 | | | |
| Total | | 372 | 127 | | | |

# CNA Benefited from L2RA Workshop Meeting Notes

# Challenges in Comparing CNA PFMs with L2RA PFMS

- ✓ L2RA Notes represent preliminary Draft Notes, not final results
- ✓ No PFMs have currently been performed for Emergency Spillway or FCO Chute by L2RA – scheduled towards the end of July
- ✓ Many L2RA PFMs rated simply as NEGLIGIBLE ($<10^{-8}$) – considered not really feasible or reasonable – many not considered fully developed in matrix as a result
- ✓ Many CNA PFMs rated simply as REMOTE ($<10^{-7}$) without estimating actual likelihood – could be much lower
- ✓ Many PFMs developed by CNA and L2RA are similar, but not exactly the same – some not carried to the same point of failure
- ✓ Many L2RA PFMs had likelihood estimates that ranged over 2 - 4 orders of magnitude; CNA Task Teams instructed to use just 1 order of magnitude

# Comparison of CNA and L2RA PFMs Developed

Preliminary

| CNA Task Team | | | | Level 2 Risk Analysis | | PFMs Able to be Compared |
|---|---|---|---|---|---|---|
| Task Teams | Facility | No. of PFMs Considered | No. of PFMs Developed | No. of PFMs Considered | No. of PFMs Developed | |
| Task 1: Emergency Spillway | Monoliths, Apron, SPW, Hillside | 34 | 9 [9] | - | - | |
| Task 3: FCO | Headworks | 89 | 31 [37] | ? | ? | |
| | Chute | | 6 | - | - | |
| Task 4: Low Level Outlets | HPP Intake | 86 | 9 | ? | ? | |
| | HPP and Switchyard | | 8 [31] | ? | ? | |
| | RVOS | | 8 | ? | ? | |
| | Palermo | | 6 | ? | ? | |
| Task 5: Embankments | Main Dam | 163 | 30 | 60 | 52 | |
| | Bidwell Bar Cyn SD | | 11 [50] | 42 [134] | 39 [104] | |
| | Parish Camp SD | | 9 | 32 | 13 | |
| Total | | 372 | 127 | | | |

? Denotes that PFMs appear to not be finalized as Fault Tree approach is being used without final results shown in the notes

# Comparison of CNA and L2RA PFMs Developed

Preliminary

| CNA Task Team | | | | Level 2 Risk Analysis | | PFMs Able to be Compared |
|---|---|---|---|---|---|---|
| Task Teams | Facility | No. of PFMs Considered | No. of PFMs Developed | No. of PFMs Considered | No. of PFMs Developed | |
| Task 1: Emergency Spillway | Monoliths, Apron, SPW, Hillside | 34 | 9 [9] | - | - | - [0] |
| Task 3: FCO | Headworks | 89 | 32 [37] | ? | ? | 12 [12] |
| | Chute | | 6 | - | - | - |
| Task 4: Low Level Outlets | HPP Intake | 86 | 9 | ? | ? | 6 |
| | HPP and Switchyard | | 8 [31] | ? | ? | 3 [17] |
| | RVOS | | 8 | ? | ? | 4 |
| | Palermo | | 6 | ? | ? | 4 |
| Task 5: Embankments | Main Dam | 163 | 30 | 60 | 52 | 26 |
| | Bidwell Bar Cyn SD | | 11 [50] | 42 [134] | 39 [104] | 10 [42] |
| | Parish Camp SD | | 9 | 32 | 13 | 6 |
| Total | | 372 | 127 | ? | ? | 71 |

# Comparison of PFM Likelihood Estimates for FCO Spillway from CNA Task Teams and L2RA Team

Preliminary

| Task Team | No. of PFMs with Same Likelihood Estimates | No. of PFMs with 1 Order of Magnitude Difference | No. of PFMs with 2 Orders of Magnitude Difference | No. of PFMs with 3 Orders of Magnitude Difference | Total No. of PFMs Compared |
|---|---|---|---|---|---|
| 1 | - | - | - | - | - |
| 3 | 8 | 2 | 1 | 1 | 12 |
| 4 | 12 | 4 | 1 | 0 | 17 |
| 5 | 20 | 20 | 2 | 0 | 42 |
| Total | 40 | 26 | 4 | 1 | 71 |

56% of PFMs with Same (Order of Magnitude) Likelihood Estimates (40/71)
93% of PFMs within 1 Order of Magnitude Difference in Likelihood Estimates (66/71)

# Update on CNA PFM Development and CNA Existing Conditions Assessment

## Presentation Outline

- **Background**
  - Review:  Purpose of the CNA
  - Risk-Informed Decision Making Approach
  - Ongoing Independent Level 2 Risk Analysis
  - Need for CNA Existing Conditions Assessment
- **Overview of CNA Existing Conditions Assessment**
  - PFM Development and Evaluation
  - Examples of PFM Development
  - Comparisons of Estimated PFM Likelihoods with L2RA Estimates
  - **Preliminary Results to Date**

# Next Steps Include:

- ✓ Internal Review of PFM Risk Estimates for consistency within and across Task Teams
- ✓ Reconcile Remaining Significant Differences between CNA and L2RA Risk Estimates
- ✓ Continue Developing Risk Reduction Measures


# Questions?