Proposed Plan for Oroville Dam Complex Level 2 Risk Analysis

20 December 2018

Project Name:

Oroville Dam Complex Level 2 Risk Analysis

Objective of Risk Analysis

This plan presents a process for an independent qualitative evaluation of the baseline dam safety risk associated with Oroville Dam.

The purpose of the Level 2 Risk Analysis is to use the Federal Energy Regulatory Commission's (FERC) Risk Informed Decision Making (RIDM) process as the Department of Water Resources seeks to understand qualitative baseline risks and to prioritize projects and needs for the Oroville Dam Complex.

Outcome Sought

The Level 2 Risk Analysis will inform the FERC Part 12D Independent Consultant inspection and evaluation of the Oroville Dam Complex, and will also complement DWR's Oroville Comprehensive Needs Assessment (CNA). The outcome of the Level 2 Risk Analysis will serve as a valuable tool supporting prioritization of projects to manage the overall risk at the Oroville Dam Complex. The results may also enhance communication of risk to the community and the diverse stakeholders of the State Water Project.

This plan incorporates potential improvements to the Potential Failure Modes Analysis process provided by the Independent Forensic Team (IFT) that was convened after the 2017 Oroville Spillway Incident. The IFT's suggested improvements are included at the end of this document. The aspects of the plan that address these improvements are noted by "(IMP#)".

United States Society on Dams (USSD)

This plan has also been developed to satisfy recently signed Federal legislation[1] that directs the Federal Energy Regulatory Commission (FERC) to require the licensee of Oroville Dam [the California Department of Water Resources (DWR)], to request the United States Society on Dams (USSD) to nominate independent consultants to prepare a Level 2 risk analysis, consistent with the FERC's risk informed decision making guidelines, for use in conducting the next Part 12D safety review of Oroville Dam. The Board of independent consultants required by FERC will be referred to throughout this document as the "10th FERC Part 12D Independent Consultants Board." The independent consultants preparing this plan and conducting the Level 2 risk analysis are separate and distinct from the 10th FERC Part 12D Independent Consultants Board.

[1] Conference Report to Accompany H.R. 5895; Energy and Water Development and Related Agencies for the Fiscal Year Ending September 30, 2019, 115th Congress, 2nd Session, Report 115-929; Energy and Water, Legislative Branch, and Military Construction and Veterans Affairs Legislations Act, 2019.

Description of Project Features

For purposes of the proposed Level 2 Risk Analysis, Oroville Dam Complex includes Oroville Dam, Edward Hyatt Powerplant, Hyatt Powerplant Intake, Bidwell Bar Canyon Saddle Dam, Parish Camp Saddle Dam, Flood Control and Emergency Spillways, the River Valve Outlet System, and the Palermo Tunnel Outlet. Each of these features will be considered in the Level 2 Risk Analysis.

Summary of Previous PFMAs

The first Potential Failure Mode Analysis (PFMA) workshop for Oroville Dam was held on September 15, 2004 and was performed in accordance with FERC Chapter 14 Engineering Guidelines dated April 11, 2003. In the 2004 PFMA workshop, one PFM was identified and developed. This potential failure mode was related to [redacted]. Additionally, four "Candidate PFMs" were described in the report along with fifteen "Risk Reduction measures" and eleven "Other Considerations". Other Considerations typically represent PFMs that were not fully developed because they were not considered credible.

In 2009, a PFMA Update was performed for Oroville as a part of the FERC Part 12D inspection. This update was performed by DWR personnel and the Part 12D Independent Consultants. The update consisted of a review of the 2004 PFMA Workshop results, the Supporting Technical Information Document (STID), and other project documents relating to operation and dam safety at Oroville Dam since the last Part 12D inspection; followed by an informal one-day workshop on September 17, 2009. Based on the review and workshop, an updated PFMA report was generated consisting of the 2004 report with revisions (insertions/deletions) called out in the report. Several modifications/additions were made to the Major Findings and Understandings, Risk Reduction Measures, and Other Considerations. Most significantly, an additional PFM was identified and included in the 2009 PFMA report. [redacted] This PFM was assigned a Category IV rating, as it seemed extremely unlikely that it could progress to dam failure.

In an effort to further understand the project and for DWR to prepare for the upcoming Risk Informed Decision Making guidelines that are being implemented by FERC, a new comprehensive PFMA was performed on Oroville Dam in 2014. The 2014 PFMA for Oroville Dam was conducted in accordance with FERC's Chapter 14 Engineering Guidelines dated July 1, 2005. While this is considered a new comprehensive PFMA, the results from the previous 2004 PFMA and the 2009 PFMA Update were considered in the new PFMA workshop. Specifically, items discussed under "Other Considerations" from the previous PFMA's were reviewed and discussed in the 2014 PFMA Workshop. Additional PFMs not previously contemplated were also considered in the 2014 PFMA.

In the 2014 PFMA the following topics were discussed at length but not identified as being significant issues of concern:

Definition of Failure

FERC engineering guidelines Chapter 14 defines Potential Failure Mode as:

> "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 impounded water. Failure Modes that result in unintended releases of water, such as the Folsom Dam radial gate failure, are also considered."

The Independent Forensic Team noted that because PFMs tend to be focused on outright failure and uncontrolled release of water, a broader interpretation and definition of failure is needed (IMP13). As such, DWR proposes to use the following definition of failure, modified from the Federal Guidelines for Dam Safety, Glossary of Terms (2004) by Federal Emergency Management Agency, for development of PFMs:

> A civil, mechanical or electrical malfunction or abnormal operation (outside the design assumptions and parameters) that adversely affects a dam's ability to impound water and leads to something greater than a "minor" consequence as defined by the Division of Operations and Maintenance's Risk Matrix.

The DWR O&M Risk Matrix referenced in the definition of failure is discussed in a subsequent section of this plan. The proposed definition of failure is generally consistent with FERC's definition of a Potential Failure Mode and is aligned with the DWR Asset Management framework.

Using the proposed definition of failure above, PFMs would be grouped on the basis of the type of failure or event and the consequence categories as described below:

1. PFMs that involve potential failure of a dam or appurtenant structure leading to an uncontrolled release of the reservoir that would result in potential life loss or economic damages in excess of $100M. [redacted] Estimates for these PFMs will be portrayed on the Oroville Level 2 Risk Analysis Matrix (described below).
2. PFMs that involve civil, mechanical or electrical component malfunctions or abnormal operations that result in the dam or appurtenant structures not performing as designed. Reservoir breach and life loss would not be associated with these PFMs but they could [redacted] and would lead to financial impacts greater than $10M. [redacted]. The Level 2 Risk Analysis Team will estimate failure likelihood for these PFMs and will communicate these PFMs to DWR to estimate all non-life loss consequences. Estimates for these PFMs will ultimately be portrayed on DWR's O&M Risk Matrix. They would not be portrayed on the Oroville Level 2 Risk Analysis Matrix because there is no life loss.
3. Non-failure and non-breach events that lead to life loss. This includes events where there is no malfunction or failure of any component or structure, but life loss is expected. These scenarios serve to document the baseline life loss consequences and will be used to determine incremental life loss estimates. This would include various flood events that are passed through Oroville Dam. Estimates for these events are portrayed on a Non-Breach Life Loss Risk Analysis Matrix similar to Figure 11 in FERC's Level 2 guidelines.
4. Non-failure and non-breach events that do not lead to life loss. This includes events where there is no malfunction or failure of any component or structure, and life loss is not expected. The Level 2 Risk Analysis Team will estimate likelihood for these events and will communicate these PFMs to DWR to estimate all non-life loss consequences. This would capture events that are related to damage of facilities at the dam from planned, as-designed operations. Estimates for these events will ultimately be portrayed on DWR's O&M Risk Matrix.

Level 2 Risk Analysis Process

FERC has developed draft guidance and procedures for periodic Level 2 risk analyses. The intent of Level 2 risk analysis is to utilize best available information and identify additional studies that would be required to refine risk estimate. The level of effort was scaled up from the minimum requirements to leverage the wealth of information available for the Oroville Dam complex. Level 2 Risk Analysis will follow the general process as outlined by FERC:

- Training of RIDM Concepts and Level 2 Risk Analysis Process: DWR initiated a first phase risk training with a workshop that was held in August 2018. However, further opportunities are needed to continue DWR's exposure to risk concepts and processes. A coordination meeting and dry-run workshop will be held in December 2018, which will be open to select participants in the proposed Level 2 Risk Analysis scheduled in the beginning of 2019. In addition to this workshop, all participants will be provided a reading assignment that will include FERC RIDM Guidelines, FEMA Federal Guidelines for Dam Safety Risk Management (P-1025), and Best Practices for Dam and Levee Safety Risk Analysis chapters relevant to the features evaluated during their participation. And to reinforce the reading assignment, at the beginning of each week of Level 2 Risk Analysis, Facilitators will provide a short introductory presentation to describe and review the proposed risk analysis process.
- Project Background Information and Presentations: As precursor to the Part 12D Independent Consultant inspections of the Oroville Dam Complex, DWR provided three full-days of background information presentations on November 5, 6 and 7, 2018. Most but not all of the Level 2 Risk Analysis participants attended or prepared these presentations. Reproductions of the presentations (and any supporting reports) will be made available to all of the Level 2 Risk Analysis participants.
- Review Project Information: (Addresses IMP1, IMP2, IMP3, IMP5) DWR has compiled and organized a significant amount of project documentation ranging from inspections reports, engineering and geologic studies, drawings, specifications, construction documentation, photographs, prior PFMA and Part 12D reports, specialized inspection results, and analyses. This information will be provided to participants electronically in advance of the workshops for their study. DWR will request that subject matter experts focus on documentation relevant to their discipline in advance of the workshop. Both DWR staff and consultants will be funded and directed to complete document review prior to the workshop. In addition, the FERC Part 12D IC Board will be provided time to meet as a group prior to and during the Level 2 Risk Analysis (Addresses IMP4). A reconnaissance-level site visit of the facilities has also been scheduled in advance of the workshops, to be attended by Facilitators, Subject Matter Experts (SMEs), and other key participants. To encourage the review of documentation and brainstorming of PFMs prior to the level 2 Risk Analysis workshops, a questionnaire will be sent to all SMEs and facilitators that must be completed and returned to DWR in advance of the risk analysis workshops (IMP2, IMP3 and IMP5). The questionnaire will address the design details and previous studies completed on the Oroville complex, will be comprehensive in demonstrating each reviewer's familiarity with the available project information, will solicit input on candidate

potential failure modes and will require input as to the adequacy of the information for use in risk analyses. Candidate questions that may be used in this questionnaire are included below.

- Background information questions (for those required to read appropriate background information)
- List key documents reviewed in detail
- List key documents reviewed in general
- In the following areas, what information did you find that is important and related to potential failure modes?
    i. General background information
    ii. Design information
    iii. Construction information
    iv. Performance information
- What information is missing that you believe is necessary for evaluation of potential failure modes and Level 2 Risk Analysis?
- What aspects of the load (normal, hydrologic, and seismic) are you least confident in that may impact development and evaluation of potential failure modes and risk estimates? What additional evaluation or investigation is necessary to increase confidence?
- What aspects of the structural performance are you least confident in that may impact development and evaluation of potential failure modes and risk estimates? What additional evaluation or investigation is necessary to increase confidence?
- What aspects of the consequences are you least confident in that may impact development and evaluation of potential failure modes and risk estimates? What additional evaluation or investigation is necessary to increase confidence?

- Develop/Review/Update Loading Estimates: A number of studies conducted over the past several years have reduced uncertainty and led to updates in hydrologic and seismic loading. Further discussion on these studies is provided below under "Engineering Analyses needed to Support Risk Analysis". DWR anticipates loading estimates to represent the current state of knowledge, understanding, and best practices.
- Presentations of Background Information: Each week of risk analysis will begin with presentations of information relevant to the features evaluated that week.
- Develop/Review/Update Potential Failure Modes: (Addresses IMP2, IMP3, IMP5, IMP6, IMP13) Using the FERC approved PFMA process, the proposed workshops will review and update, if needed, all previous PFMs from the 2014 PFMA workshop. The plan also provides opportunity to develop new PFMs via survey prior to the workshop and brainstorming sessions during the workshop.
- Evaluate Identified PFMs: Using the FERC approved PFMA process, the proposed workshops will assess previous and newly proposed PFMs. The plan includes evaluation and screening of PFMs to ensure that workshop time and energy is not expended on non-credible PFMs (Addresses IMP6).
- Develop Consequence Estimates: This plan proposes the use of the USACE LifeSIM software, in which a model for potential breaches of the Oroville facility have already been modeled to bracket the understanding for potential life loss. Reclamation Consequences Estimating Method (RCEM) will be used to fill any gaps during the Level 2 Risk Analysis for PFMs not modeled in

LifeSIM, with LifeSIM life loss estimates included as points to be considered on the RCEM fatality rate charts. Further, DWR's Asset Management has developed Consequence categories that will be informed by the LifeSIM results. Additional discussion is provided below.

- Develop Failure Likelihood and Consequence Categories: Factors making the PFM more likely and less likely will be identified, along with key factors and supporting studies and references. The frequency of loading will be considered to estimate likelihood, while inundation mapping and LifeSIM results will be utilized to estimate consequences. These estimates will be achieved through iterative blind voting and discussions as necessary (Addresses IMP11).
- Develop Risk Estimate: The expanded O&M risk matrix (See Figures 2 and 3) will be utilized to estimate and portray each PFM's risk. Uncertainty in the PFM's risk will be captured by expanding its footprint on the matrix. This will follow the process commonly referred to in Best Practices as semi-quantitative risk analysis (SQRA), which considers loading frequency, failure probability, and consequences with rough, general estimates that can span orders of magnitude of uncertainty for any given PFM. The Level 2 Risk Analysis process can be performed with any level of information available, with a potential outcome being a better understanding of uncertainty and where more studies would contribute to a more refined estimate of risk that could be used to better make risk-informed decisions.
- Identify Critical Load Cases/Ranges: The Level 2 Risk Analysis process will facilitate the identification of the load ranges that are likely to be most critical for each potential failure mode. This will be done by considering the likelihood of the event that causes a structural response that is other than the design intent, combined with the likelihood of adverse response to that loading condition. It is acknowledged that the critical load ranges may not be the largest and less frequent MCE and PMF loading conditions. There may be potential to significantly impact the downstream population at lower, more frequent earthquakes and/or floods, which may control risk-informed decision making processes.
- Develop Potential Interim Risk Reduction Measures and Management Actions: The workshop will include time to identify and discuss risk reduction measures and actions. The risk reduction will not be quantified as part of this Level 2 Risk Analysis, but at a later date and as a separate effort, the CNA project will use this information to develop specific measures and combinations of measures to reduce risks.
- Document Results: Dedicated recorders will capture the workshop information to allow the facilitators to conduct an efficient workshop. The recorders and facilitators will author the Level 2 Risk Analysis reports that will be submitted to FERC in lieu of the standard PFMA report.

Figure 4 shows a flow chart that represents the general proposed process and the key components to be considered as the Level 2 Risk Analysis team moves forward.

Proposed Risk Team Members and Workshops

The team chosen for this Level 2 Risk Analysis will prepare an independent evaluation of the facility, as described in the Federal legislation. For this reason, beyond solicitation of the USSD nominations, DWR has gathered dam safety RIDM industry expertise from private sector and Federal agencies. The individuals associated with Federal agencies which are recommended in this proposal are key to the

process. However, the participation of these people and their commitment as resources, if supported by FERC, requires specific agreements with the associated Federal agencies. DWR is currently negotiating with the respective agencies.

The following team is proposed for the Level 2 Risk Analysis in 2019. Due to the magnitude of the effort, the team proposes that the Level 2 Risk Analysis be split into five (5) sessions, grouped by common features to schedule and leverage appropriate disciplines and expertise as much as possible. The Level 2 Risk Analysis team is comprised of individuals nominated by USSD, industry experts, and select technical experts within DWR that can provide the most in-depth knowledge of the facility. Table 1 lays out the proposed Facilitators, Subject Matter Experts, and additional support staff for each of the five workshops.

Table 1: Proposed Resources for Oroville Level 2 Risk Analysis

Proposed Resources for Oroville Level 2 Risk Analysis																
Week	Features Considered	Failure Likelihood Estimating SMEs				Loadings and Consequences SMEs			PFM Development	Level 2 Risk Analysis Facilitators			Recorders	Board Representation	Oversight	Deliverable
		Geotechnical	Civil/Structural	Geology	Mechanical/ Electrical	Hydrology	Seismology	Consequences		Geotechnical	Structural	Mechanical/ Electrical				
	Site Visit: January 14-16, 2019	*All those that have not previously been involved in a site visit must participate in a site visit, for the features they will be involved with, prior to the start of the Level 2 Risk Analysis*														
1	Parish Camp, Bidwell Bar Canyon, and Main Embankments: January 22-25, 2019	Mark Stanley Robin Fell David Paul	Phoebe Percell	Chris Hitchcock Keith Kelson Bill Cole	N/A	Nathan Pingel and/or Paul Risher David Ford	Keith Kelson and/or Dina Hunt	Jason Needham and/or Paul Risher Joe Goldstein	Dean Durkee	Dan Osmun	N/A	N/A	Elena Sossenkina* and/or Matt Balven	10th Part 12D ICs CNA IRB	Eric Halpin and/or Steve Townsley as needed	Level 2 Risk Analysis Report
2	Main Embankment: January 28 - February 1, 2019	Mark Stanley Robin Fell David Paul	Phoebe Percell	Chris Hitchcock Keith Kelson Bill Cole	N/A	Nathan Pingel and/or Paul Risher David Ford	Keith Kelson and/or Dina Hunt	Jason Needham and/or Paul Risher Joe Goldstein	Dean Durkee	Dan Osmun	N/A	N/A	Elena Sossenkina* and/or Matt Balven	10th Part 12D ICs CNA IRB		
3	Hyatt Intake, FCO Headworks, and Palermo Tunnel Outlet: February 27 - March 1, 2019 and March 4, 2019	Dan Osmun	Tom Hepler and/or Todd Schellhase Keith Moen	Bill Cole Keith Kelson	Rick Schultz* Alex Bjelica	Nathan Pingel and/or Paul Risher David Ford	Keith Kelson	Jason Needham and/or Paul Risher Joe Goldstein	Bill Fiedler	N/A	Phoebe Percell	Rick Schultz and/or Bill Fiedler	Elena Sossenkina and/or Matt Balven	10th Part 12D ICs CNA IRB		
4	FCO Headworks, Hyatt Powerplant and River Valve Outlet System: March 5-7, 2019	Dan Osmun	Todd Schellhase Phoebe Percell* Keith Moen	Bill Cole Keith Kelson	Rick Schultz* Alex Bjelica	Nathan Pingel and/or Paul Risher David Ford	Keith Kelson	Jason Needham and/or Paul Risher Joe Goldstein	Phoebe Percell	N/A	Bill Fiedler	Rick Schultz and/or Bill Fiedler	Elena Sossenkina and/or Matt Balven	10th Part 12D ICs CNA IRB		
5	Post-Construction FCO Chute and Emergency Spillway: March 18-22, 2019	Dan Osmun	Tom Hepler Phoebe Percell* Keith Moen	Bill Cole Keith Kelson	N/A	Nathan Pingel and/or Paul Risher David Ford	Keith Kelson	Jason Needham and/or Paul Risher Joe Goldstein	Phoebe Percell	N/A	Bill Fiedler	N/A	Elena Sossenkina and/or Matt Balven	10th Part 12D ICs CNA IRB Recovery Board		Post-Construction Recovery Level 2 Risk Analysis Report

Full time	Participating in PFM development and estimating PFM likelihood and consequence categories on matrix
As needed	Subject Matter Experts may be present and may provide estimates when necessary and appropriate
	Loading specialists will not be estimating PFM categories on matrix, but will participate in discussions relevant to hydrologic or seismic loads

Notes:
N/A means an SME or Facilitator in this discipline is not needed for this week
Where "and/or" is noted - multiple names are identified but not all SMEs are needed to participate for all 5 weeks. This provides options for each week.
Loadings and Consequences SMEs will be available to provide input on their specialties, but will not be estimating failure likelihood for PFMs
*indicates resources that will be rotated in and out of the SME role as needed for contributions to specific potential failure modes. These resources may become a facilitator or note taker for potential failure modes when not an SME. At no time will these resources be expected to fill two roles for any given potential failure mode.

The risk workshop sessions have been planned to adequately cover all relevant technical disciplines with a diverse group of subject matter experts and address the burnout factor associated with long consecutive workshops (IMP7, IMP8, IMP9, and IMP15).

Though DWR considers the selected USSD nominees and industry experts as an independent team, the products of this Level 2 Risk Analysis will be reviewed by multiple independent Boards. The input from these different Board perspectives will contribute to a useful and reliable product which DWR can use in future decision making.

Some individuals listed in Table 1 have already been placed under contract with DWR. In light of the proposed draft legislation requiring the Level 2 Risk Analysis, DWR immediately and proactively began resource planning and procurement efforts to help ensure that a quality risk analysis could be completed in conjunction with the FERC Part 12D Independent Consultant inspection and evaluation of the Oroville Dam Complex.

As there are many interested parties for this project, DWR anticipates many attendees at each Level 2 Risk Analysis workshop. The room will contain observers, decision makers, technical specialists, Subject Matter Experts, recorders, facilitators, advisors/oversight, and members of up to three separate independent Boards (10th FERC Part 12D Independent Consultants Board, CNA Independent Review Board and the Spillway Recovery Board of Consultants). For this reason, the roles and responsibilities of each attendee must be clear and understood by all. The qualifications and responsibilities of each key role are listed in Table 2 and Table 3, respectively, and will be clearly communicated to all that are in attendance at each Level 2 Risk Analysis workshop. DWR will submit, for FERC's review and approval, the resumes of each risk analysis team member as delineated within Table 1 (Addresses IMP11).

The experience and expertise of DWR is vital to informing the Level 2 Risk Analysis process, and for that reason, technical experts from DWR have been identified to contribute to the risk estimates during the risk analysis. Estimates from DWR will be made and submitted using cards that are of a varying color from the independent SMEs participating in the workshop. This will assist in preparation of the independent risk analysis report.

The Part 12D Independent Consultants and others participating in the role of oversight/advisor are considered to be reviewers for the Level 2 Risk Analysis, and are free to attend all risk workshops associated with this effort, provide input as the workshop occurs on any insight that may impact the outcome. In general, in order to create an independent review of the Level 2 Risk Analysis, they will not be estimating members of the risk analysis during the risk estimation process. However, the workshop facilitators are allowed the flexibility to incorporate Part 12D Independent Consultant input as needed to enhance the quality of the process and conclusions

Table 2: Experience Criteria for Level 2 Risk Analysis Key Roles (Addresses IMP11)

Role	Experience Criteria
Facilitator	1. Dam Safety Experience – The risk analysis facilitator should have a minimum of 15 years of experience in their field of expertise related to dam engineering/dam safety. This experience should include design/analysis experience and a familiarity with key dam safety failures and incidents. 2. Risk Analysis Experience – The risk analysis facilitator should have participated as a subject matter expert on at least 2 team risk analyses (Level 2 or higher), have been the primary author of at least 2 risk analysis reports (Level 2 or higher). 3. Training – The risk analysis facilitator shall have attended the Best Practices in Dam Safety Risk Analysis training presented by the Bureau of Reclamation and the USACE.
Co-Facilitator	1. Dam Safety Experience – The risk analysis co-facilitator should have a minimum of 10 years of experience in their field of expertise related to dam engineering/dam safety. This experience should include design/analysis experience and a familiarity with key dam safety failures and incidents. 2. Risk Analysis Experience – The risk analysis facilitator should have participated as a subject matter expert on at least 2 risk analyses (Level 2 or higher) and have been the primary author of at least 2 risk analysis reports (Level 2 or higher). 3. Training – The risk analysis facilitator shall have attended the Best Practices in Dam Safety Risk Analysis training presented by the Bureau of Reclamation and the USACE.
Recorder	1. Dam Safety Experience – The risk analysis meeting recorder should have a minimum of 5 years of experience in their field of expertise related to dam engineering/dam safety. This experience should include design/analysis experience and a familiarity with key dam safety failures and incidents. 2. Risk Analysis Experience – The risk analysis recorder should have participated as an observer in at least 2 risk analyses (Level 2 or higher) or have served in a higher level role in a risk analysis.
Subject Matter Experts (SMEs)	1. Dam Safety Experience – SMEs should have a minimum of 10 years of experience in their field of expertise related to dam engineering/dam safety. This experience should include design/analysis experience and a familiarity with key dam safety failures and incidents. 2. Training – SMEs should be familiar with the content of the Best Practices in Dam Safety Risk Analysis training presented by the Bureau of Reclamation and the USACE, especially those chapters related to their area of expertise.
Oversight Role	1. Dam Safety Experience – The individuals providing oversight of the Level 2 risk analysis process should have a minimum of 20 years of experience in related to dam engineering/dam safety. This experience should include design/analysis experience, a familiarity with key dam safety failures and incidents, and experience in managing a dam safety program and making dam safety decisions. 2. Risk Analysis Experience – The oversight reviewers should have participated in at least ten risk meetings in which risk results are presented and which result in dam safety decisions.

Table 3: Roles and Responsibilities for Level 2 Risk Analysis Key Roles

Role	Responsibilities
Facilitator	1. Pre-Risk Analysis Activities – The risk analysis facilitator should participate in a recent site visit (within the past 12 months) of the facilities that will be evaluated in the risk analysis meeting. The facilitator should review pertinent records relating to the design, analysis, construction and performance of the facilities that will be evaluated in the risk analysis meeting. The facilitator should also be involved in discussions of any specific studies for the risk analysis, to ensure that critical information can be incorporated into the meeting discussions. 2. Risk Analysis Meeting – The risk analysis facilitator facilitates the risk analysis meeting, helping the team evaluate the available information, developing strategies for estimating risk and soliciting and achieving consensus on the ranges of likelihood and consequence estimates. 3. Post Risk-Analysis Meeting – The risk analysis facilitator should review the risk analysis report for completeness, thoroughness, accuracy and confirm that the work and risk analysis calculations are in accordance with sound risk analysis principles. The facilitator should also ensure that the dam safety case is well developed and is consistent with the available information.
Co-Facilitator	1. Pre-Risk Analysis Meeting – The risk analysis co-facilitator should participate in a recent site visit (within the past 12 months) of the facilities that will be evaluated in the risk analysis meeting. The co-facilitator should review pertinent records relating to the design, analysis, construction and performance of the facilities that will be evaluated in the risk analysis meeting. 2. Risk Analysis Meeting – The risk analysis co-facilitator assists the facilitator as needed during the risk analysis meeting. In some cases, a co-facilitator can serve multiple roles during the risk meeting. 3. Post Risk-Analysis Meeting – The risk analysis co-facilitator should review the risk analysis report for completeness and accuracy.
Recorder	2. Risk Analysis Meeting – The risk analysis recorder captures, in writing, the key discussions and concepts during the risk analysis. The recorder will use a computer projector to display what is being recorded in real-time during the risk analysis meeting. 3. Post Risk-Analysis Meeting – The recorder provides organized notes and tables summarizing the risk discussions for incorporation into the risk analysis report.
Subject Matter Experts (SMEs)	1. Pre-Risk Analysis Meeting – SMEs should review pertinent records relating to the design, analysis, construction and performance of the facilities that will be evaluated in the risk analysis meeting. They should also review appropriate chapters from the Best Practices in Dam Safety Risk Analysis training presented by the Bureau of Reclamation and the USACE, especially those chapters related to their area of expertise. 2. Risk Analysis Meeting – The SMEs should actively participate in the discussions of the potential failure modes and should provide judgements of risk matrix categories during the solicitation process. 3. Post Risk-Analysis Meeting – The SMEs should review the risk analysis report for completeness and accuracy.

Oversight Role	1. Pre-Risk Analysis Meeting – The oversight reviewers should review the proposed plan for the Level 2 risk analysis and provide comments in advance of the risk analysis meetings. 2. Risk Analysis Meeting – The oversight reviewers are free to attend and observe the risk analysis meetings as available. Any significant concerns about the process should be relayed to the facilitator/DWR during the meeting. 3. Post Risk-Analysis Meeting – The oversight reviewers should provide a written report to DWR that documents their findings regarding the overall process and provide recommendations for future improvements to the process. Their key role is to provide insight to whether the risk process follows industry standards for best practices.

Proposed Risk Analysis Matrix

A risk matrix developed by DWR has been combined with a dam safety risk matrix common to the dam safety industry. The matrices combination was developed and tested during a workshop in August 2018 that included DWR, FERC, and additional dam safety experts.

The FERC's draft Level 2 Risk Analysis Procedures (version 1.1) includes a risk analysis matrix to portray societal incremental life safety risk (Figure 9 in FERC's Level 2 risk analysis procedures document). The FERC Level 2 risk matrix is shown below, with quantitative ranges of failure likelihood and incremental life loss values added from Tables 2 and 5 of the FERC Level 2 procedures document.

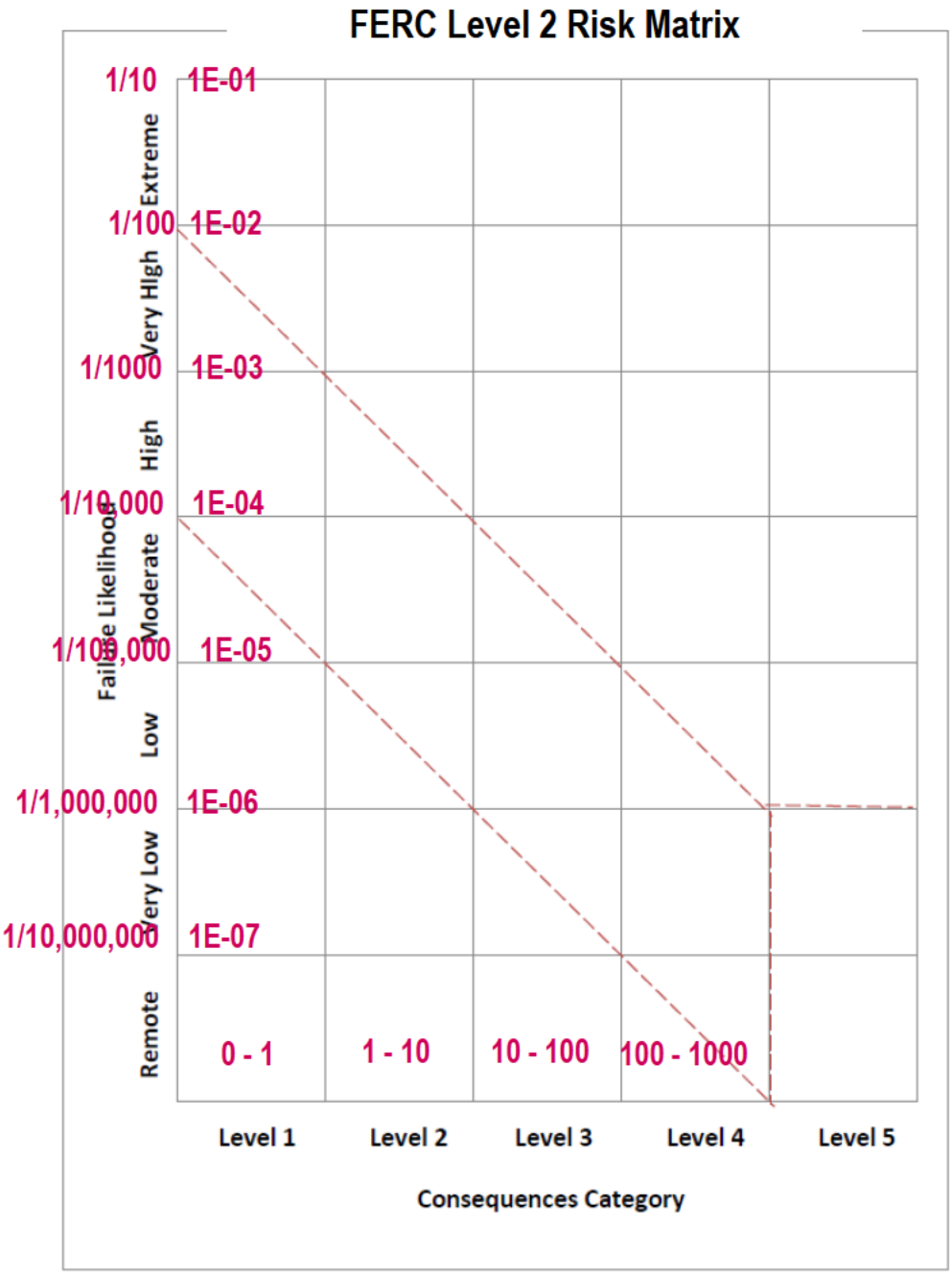

Figure 1 - Modified from Figure 9 of FERC Level 2 Risk Analysis draft procedures

DWR's Division of Operations and Maintenance (O&M) adopted a risk matrix for asset management purposes that is very similar to BC Hydro's corporate risk matrix as shown on Figure 2 below.

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						

[redacted]

Figure 2 – DWR Division of Operations and Maintenance Risk Matrix

For purposes of managing overall agency risks including dam safety risk, DWR has elected to portray dam safety risks on a modified version of the risk matrix Figure 2. The risk matrix was modified to include additional (more remote) likelihood categories and additional life loss categories that capture the necessary ranges of values that are needed to portray dam safety risk.

The boxes in the risk matrix (Figure 2) include recurrence descriptors that correlate to the lines on the FERC Level 2 risk analysis matrix (Figure 1). For example, for a likelihood category of 2 (1/1,000 to 1/10,000 year recurrence) directly corresponds to the "High" failure likelihood category on the FERC Level 2 risk analysis matrix. Using this direct mapping approach, the 6x6 matrix shown below as Figure 3 is proposed for the Oroville Level 2 risk analysis.

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

Notes:

1. This matrix is being used to portray both Annual Failure Probability and Societal Risk.
2. DWR O&M risk matrix includes up to consequence category 7. Higher consequence categories are not defined in the asset management framework.
3. FERC Draft Level 2 Risk Analysis Procedures document includes up to life loss consequence category 5 (>1,000). Higher consequence categories are not defined in the draft Level 2 document.

Figure 3 - Proposed Oroville Level 2 Risk Analysis Matrix

To demonstrate comparability and compatibility with both DWR asset management matrix and the FERC Level 2 risk analysis matrix, the proposed matrix on Figure 3 includes descriptors from both matrices. FERC's failure likelihood descriptors are included along with quantitative ranges of likelihood that can be mapped to DWR's risk matrix. For example, the FERC failure likelihood descriptor "moderate" corresponding to a quantitative range between 1E-05 and 1E-04 can be directly mapped to the DWR risk matrix likelihood category 1. The FERC categories of "Low," "Very Low," and "Remote" are associated with lower likelihoods than currently exist on the DWR asset management matrix.

Similarly, the proposed matrix on Figure 3 includes the descriptors of both the DWR risk matrix consequence categories and the corresponding FERC Level 2 consequence categories, along with the quantitative ranges of incremental life loss corresponding to each category. The highest consequence category that exists on the DWR risk matrix is category 7 (representing "multiple fatalities") but additional consequence categories are necessary to capture the range of dam safety risks. In addition, the highest FERC Level 2 risk matrix consequence category is Level 5 (1,000 – 10,000) but for Oroville Dam, some PFMs may have the potential for incremental life loss greater than 10,000 so one additional consequence category was added to the matrix.

Overall, the proposed matrix on Figure 3 is comparable and compatible with the FERC Level 2 risk analysis matrix and is consistent with the intent of DWR's risk matrix such that dam safety risks can be portrayed with other agency risks on an extended version of the DWR O&M matrix (Addresses IMP10). Non-breach scenarios estimated as part of this effort will be portrayed on a separate non-breach risk matrix similar to the one shown on Figure 11 of the FERC Level 2 document.

Consideration of IFT's Oroville Spillway Incident PFMA Improvements

Related to the PFMA process, the IFT's Oroville Spillway Incident report provided a list of potential improvements for consideration within Chapter 10 of Appendix F3. The list of suggested improvements is provided below for reference. Aspects of the plan that address the improvements are noted throughout the document.

- **IFT PFMA Improvement #1 (IMP1)**: Provide more lead time to review documentation so that consultants and other participants can request additional information if documents provided are incomplete.
- **IFT PFMA Improvement #2 (IMP2)**: Pre-prepare PFMs prior to the workshop
- **IFT PFMA Improvement #3 (IMP3):** The brainstorming sessions could be performed electronically prior to the workshop
- **IFT PFMA Improvement #4 (IMP4)**: Provide the Independent consultants with time to meet as a separate group, prior to the full workshop attended by all participants
- **IFT PFMA Improvement #5 (IMP5)**: Develop a "master-list" of generic potential failure modes which serve as a starting-point and checklist for developing project-specific PFMs, reflecting knowledge of failure modes which have actually occurred in the past – but do not allow the master list to limit the scenarios for PFMs which are developed and considered.
- **IFT PFMA Improvement #6 (IMP6)**: To identify potential failure modes, combine brainstorming with a more structured approach during workshops.

- **IFT PFMA Improvement #7 (IMP7)**: Ensure that the PFMA team is diverse and adequately covers all relevant technical disciplines with sufficient specialized expertise (e.g., although a structural engineer was present in the 2014 PFMA, there was apparently no engineer present who specialized in hydraulic structures).
- **IFT PFMA Improvement #8 (IMP8)**: Divide the PFMA into smaller, more specialized groups for different components of complex dam systems, but do not lose coordination on interactions between components. This would be an alternative to a single large group with different interests and specialties being together for a single PFMA workshop (e.g. one team for the dam, another for the spillways).
- **IFT PFMA Improvement #9 (IMP9)**: Address the burnout factor associated with mental fatigue resulting from a long workshop process (e.g. break of the workshop into a series of separate workshops).
- **IFT PFMA Improvement #10 (IMP10)**: Reconsider the definitions of the four FERC PFMA risk categories, and possibly increase the number of categories in order to make finer distinctions.
    - *Facilitation team response: This recommendation is not applicable. PFM categories will not be used in the Level 2 Risk Analysis. Instead the risk matrix will be used to portray risk.*
- **IFT PFMA Improvement #11 (IMP11)**: If a voting process is used, consider including the qualifications needed to be able to cast a vote for particular PFMs, and possibly use silent voting so that participants are not influenced by the votes of others. Alternative, and in the IFT's opinion preferably, assign PFMs to categories based on consensus, with outlying opinions recorded appropriately if full consensus is not achieved.
- **IFT PFMA Improvement #12 (IMP12)**: Assure that the STID adequately covers all system components, and includes a history of repairs and their performance for all system components.
    - *Facilitation team response: This suggestion is not applicable to the scope of Level 2 Risk Analysis.*
- **IFT PFMA Improvement #13 (IMP13)**: Broaden the scope of failure modes considered in the PFMA process beyond those which necessarily result in uncontrolled release of water, but which may still have serious consequences for the dam owner, the public, other stakeholders, and the environment.
- **IFT PFMA Improvement #14 (IMP14)**: Supplement the PFMA by way of an FMEA or similar process for complex structures (e.g. gated spillways).
- **IFT PFMA Improvement #15 (IMP15)**: Assure that appurtenant structures get appropriate attention, commensurate with their significance.

Engineering Analyses Needed to Support the Risk Analysis

Level 2 risk analysis will utilize best available information for estimating loading, system response and potential consequences. There is a wealth of information available for the project for the risk analysis team to draw upon.

- The Level 2 risk team plans to develop and have agreement on basic probabilistic hydrologic hazard. For example, if the PMF is about a 1/10,000 year flood, additional flood frequency information will be needed (ideally good information on the magnitude and frequency of more

common floods up to the 100 or 200-year level and then some estimates on the frequency and magnitude of floods in between the 100- or 200-year flood and the PMF). Once the flood frequency curve is developed, hydrographs would need be developed, flood routings performed and corresponding reservoir elevations determined in order to be able to estimate hydrologic PFM risks.

- Inundation studies to understand impacts of variations related to potential failure modes and operation conditions. The Level 2 Risk Analysis team is establishing a matrix of studies to better understand what inundation scenarios are available. Based on anticipated PFMs, the CNA leads may determine that additional inundation scenarios are necessary for LifeSIM, and those scenarios will be prioritized by the Level 2 Risk Analysis facilitators if not enough time is available to complete all requests before the Level 2 Risk Analysis sessions. [redacted]. Various peak inflows vs. return periods are needed, along with associated hydrographs that can be routed given different operational scenarios.
- Develop consequences using the USACE LifeSIM software, with which potential breaches of the Oroville facility have already been modeled. USACE has provided the model to DWR. The Level 2 Risk Analysis team will use LifeSIM and develop consequence estimates for various breach and non-breach flooding scenarios. The results obtained from LifeSIM will be used to bracket the consequences estimates and inform better use of RCEM (additional data points on the RCEM graphs) for each individual PFM during the Level 2 Risk Analysis. A matrix of LifeSIM analyses is currently being developed to bracket the potential inundation scenarios that could be considered in the Level 2 Risk Analysis.
- DWR has tasked Lettis Consultants International (LCI) with a probabilistic seismic hazard analysis study. DWR and LCI have also consulted with Pacific Gas and Electric (PG&E) and are leveraging the PG&E seismic source model for this study. Recently collected shear wave velocity data and fault investigation findings will also inform this study. The results of the study are anticipated to be available in early 2019.
- For structural response, the Level 2 Risk Analysis team will use the results of embankment studies, FCO studies and other engineering studies that provide some indication of how the structures will perform under normal operating condition, hydrologic loading, and earthquake loadings.
- Risk Analysis team experts must agree on how to handle levees downstream. Current inundation models allow levees to overtop but they do not fail. Level 2 risk analysis will use the existing inundation maps with the understanding of the limitations of the underlying assumptions. Sensitivity hydraulic modeling with different assumptions about levee performance could be performed to help inform consequence estimating.
- Develop preliminary list of risk reduction measures for structures. Develop basic descriptions and sketches for numerous measures so that after the FERC Level 2 Risk Analysis is completed, the CNA process can proceed more rapidly with evaluation of risk reduction alternatives.
- Perform dry run workshop with sample PFMs.

Proposed Schedule

Level 2 Risk Analysis sessions are currently scheduled as follows.

- PFMA/Level 2 risk analysis coordination session and dry run with facilitators **(December 2018)**
    - Facilitation team meets to exercise specific process for review/identification/voting on PFMs, identification of critical PFMs, process for Level 2 Risk Analysis evaluation, and use of RCEM/LifeSIM information in estimating consequences.
- PFMA/Level 2 risk analysis workshop sessions every week will focus on specific features. The following dates are tentatively identified for the listed features:
    - January 22-25, 2019: Bidwell Bar Canyon and Parish Camp Saddle Dams, and Oroville Dam embankment
    - January 28-February 1, 2019: Oroville Dam embankment (cont.)
    - February 27-March 1, and March 4, 2019: Intake, FCO headworks, and Palermo Tunnel Outlet
    - March 5-7, 2019: Hyatt Powerplant and River Valve Outlet System
    - March 18-22, 2019: Post construction Oroville FCO chute and emergency spillway

Possible Outcomes from PFMA Level 2 Risk Analysis

It is important to note that the FERC Level 2 risk analysis procedures document indicates that typically the results from a Level 2 risk analysis will not be suitable for determining if the dam safety risks are tolerable. Possible outcomes from the Level 2 risk analysis are summarized below.

- All PFMs are recorded, documented, and portrayed on the risk matrix.
- For PFMs that have low risk, with high confidence in the risk level, there would be no further action; or possibly additional actions with a lower priority.
- For PFMs that have low risk to moderate risk, with low confidence in the risk level, there may be follow up actions such as new monitoring [redacted] or engineering studies to reduce uncertainty, better define risk, and increase confidence in the risk level (see Engineering Studies bullet below).
- For PFMs that have high risk with high confidence in the risk level, immediate interim risk reduction measures might be justified. However, it is unlikely that risks levels would be judged to have high confidence with a Level 2 risk analysis effort. Long term risk reduction measures might involve structural modifications or replacement. Additional engineering studies to better define the risk are likely not justified, and engineering efforts should focus on risk reduction.
- For PFMs that have high risk with low confidence in the risk level (this can occur because lack of sufficient information can lead people to be over conservative when estimating risk level), interim risk reduction measures might be considered (each situation is different) [redacted] Follow up actions would focus on actions such as new monitoring [redacted] investigations or engineering studies to better define the risk, reduce uncertainty and increase confidence in the risk level (see studies bullet below).

- Engineering Studies: Engineering studies to better define risk, reduce uncertainty and increase confidence might be phased, starting with a simplified approach and increasing in complexity only as needed. Field investigations (e.g. concrete coring and testing; geotechnical drilling), as necessary, will be conducted to collect data to support engineering studies. Factors brought out during the PFMA / Level 2 risk analysis will help inform what type of study and the scope of the studies that are needed. After studies are completed, subsequent risk analyses might indicate risk levels for PFMs could remain the same (with reduced uncertainty and/or greater confidence) or could change. If risk levels decrease, no further action is needed (or action becomes low priority). If risk levels increase, follow up actions might include interim risk reduction measures and/or long term structural modifications to reduce risk.

Post Level 2 Risk Analysis Sessions – Follow up discussions

DWR is planning a number of smaller group meetings to finalize the risk analysis, discuss information gaps or unresolved issues, and plan any next steps necessary to resolve issues or gaps. These discussions will likely also inform the Oroville CNA projects.

DWR will also bring forward outstanding asset management concerns and other operational issues that do not qualify as dam safety issues, with the purpose of being able to portray a relatively complete risk portrayal of dam safety and non-dam safety risks including asset management concerns. Although this information will not need to be submitted to FERC, it is included in discussions to advise the holistic decision-making process for DWR.

Deliverables

As indicated under the "Proposed Risk Team Members and Workshops" section, two Level 2 Risk Analysis reports will be delivered. Our rationale is to provide each respective Board (Part 12D Board vs Spillway Recovery Board) a deliverable specific that matches their respective scopes.

1. PFMA/Level 2 risk analysis Report for Oroville Dam, Hyatt Powerplant, Penstocks, and Intake Structure, the Flood Control Outlet Gate Structure, Palermo Tunnel, Parish Camp Saddle Dam, and Bidwell Bar Canyon Saddle Dam. Per prior discussions with FERC, these facilities represent the scope of the incoming 10th Part 12D Co-Independent Consultants. This report will be assessed and discussed in the 10th Part 12D Safety Inspection Reports for Oroville Dam, Bidwell Bar Canyon Saddle Dam, and Parish Camp Saddle Dam.
2. PFMA/Level 2 risk analysis Report for New Spillway Chute and Emergency Spillway: This report will serve as the post-construction assessment of these features. The Spillway Recovery Board will participate in this portion of the workshop and provide a Board Report assessing this Level 2 Risk Analysis report.

Beyond the Boards, both reports will be utilized by DWR and the Oroville Dam Complex CNA teams. The reports' combined results will serve as a baseline risk assessment of the Oroville facilities. Proposed measures developed under the six CNA tasks can then be assessed and compared in terms of how effective they are in reducing risk.

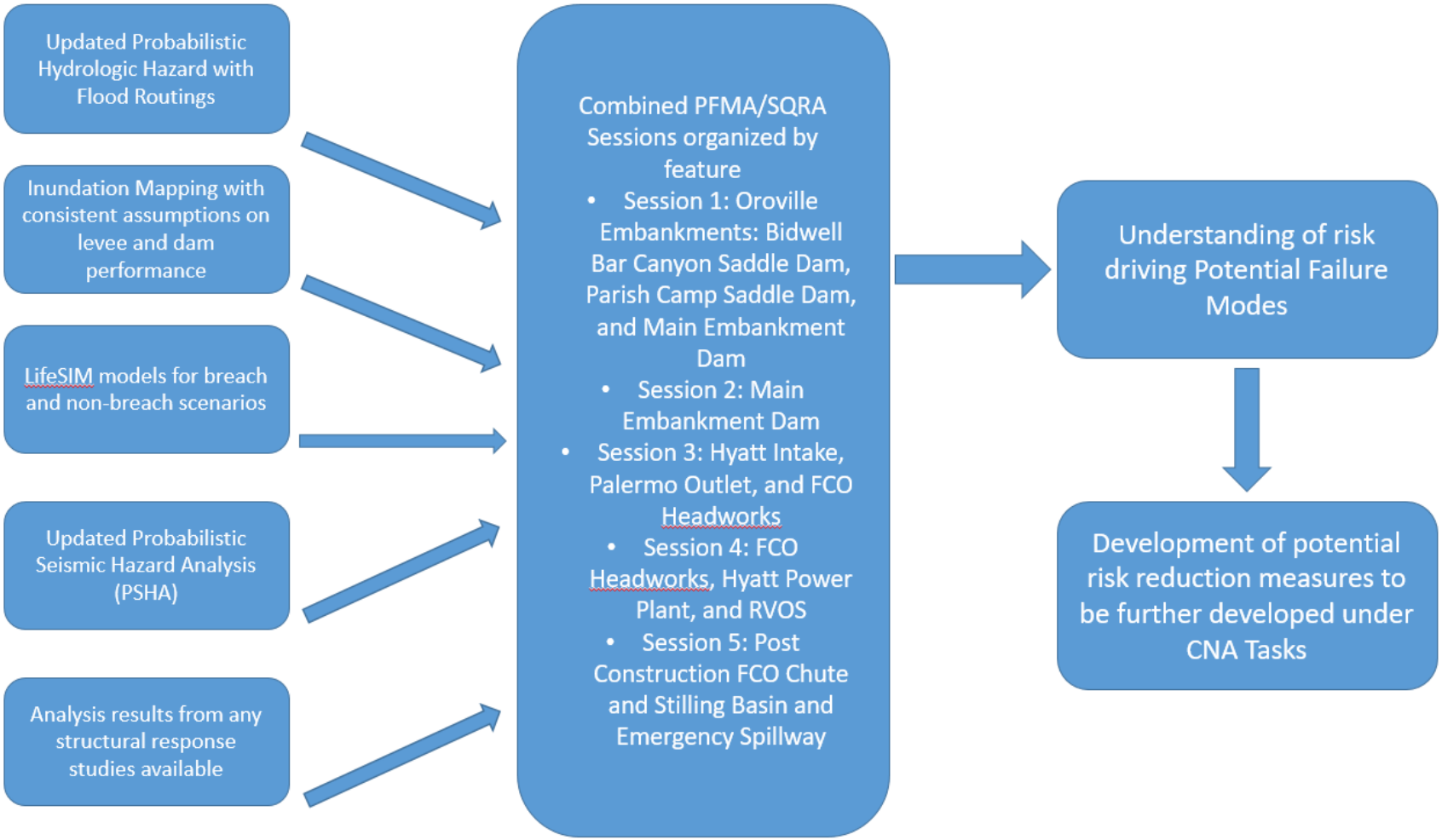

Figure 4: Flow Chart of Level 2 Risk Analysis Process for Oroville Complex

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