BUREAU OF RECLAMATION

Dam Safety Risk Analysis and Risk Management Practices at the Bureau of Reclamation

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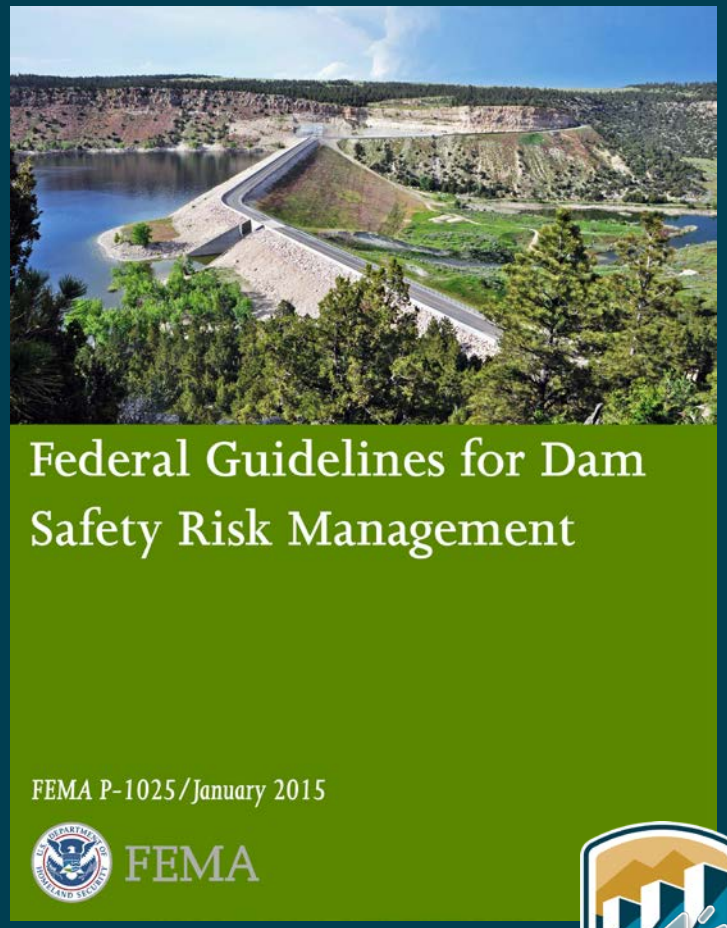
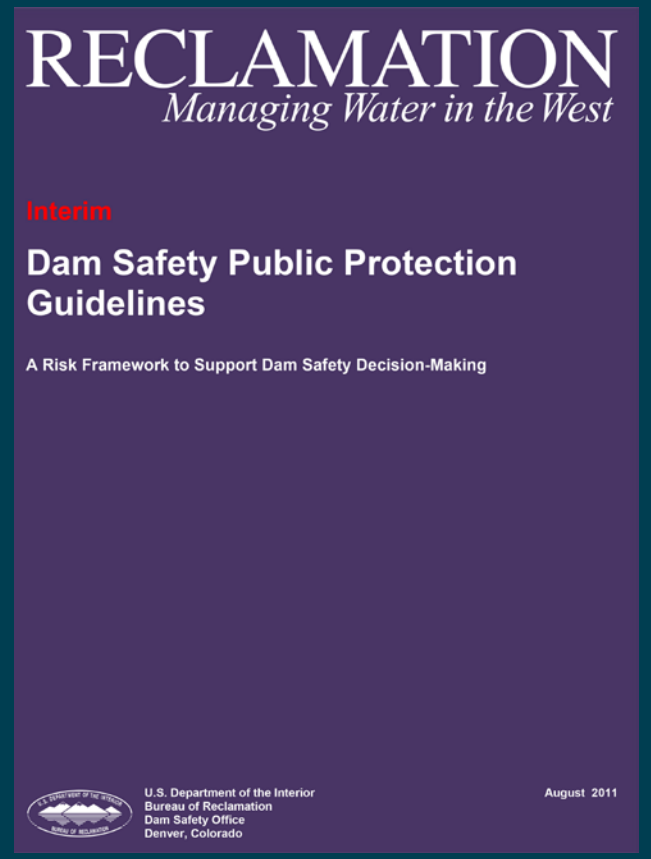
Overview of U.S. inventory of dams

- U.S. inventory consists of federally regulated, state regulated, and unregulated (typically small, low-hazard) dams
- Requirements for state regulated dams vary by jurisdiction
- Dam safety risk management for federally regulated dams is governed by Federal Emergency Management (FEMA) 1025. (Federal Dam Safety Guidelines)



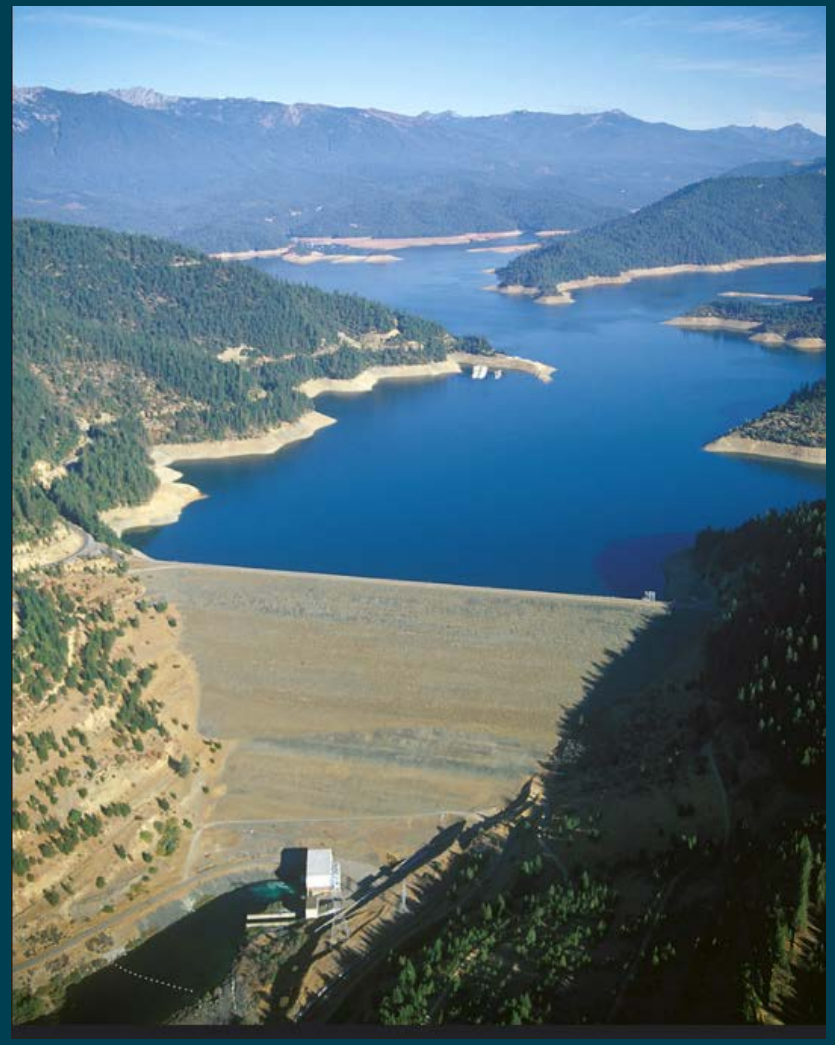
Federal Dam Safety Guidelines

- FEMA 1025 calls for risk informed decision making (RIDM) to be used to manage risks posed by dams, but does not prescribe any specific methodology
- As a result, each Federal agency with administrative dam safety responsibility has its own RIDM guidelines
- Examples include the 2011 Public Protection Guidelines (Reclamation), ER 1110-2-1156 (U.S. Army Corps of Engineers), and the Federal Energy Regulating Commission (FERC) RIDM guidelines.



Definitions

- RIDM: A decision making process that considers design information, field data, performance observations, and analysis results, as well as the estimated risk of adverse performance
  - The RIDM processes used by the major federal agencies are very similar (to the extent that joint risk analysis training is held for Best Practices)
  - Reclamation's RIDM process consists of risk analysis, risk assessment, and risk management



Definitions

- Risk: The estimated likelihood of adverse performance (dam failure) or the likelihood of adverse societal consequences (life loss)
  - Basic unit of meaning is the individual facility (as defined in authorization)
  - Basic unit of time is a typical project year (risks are annualized)

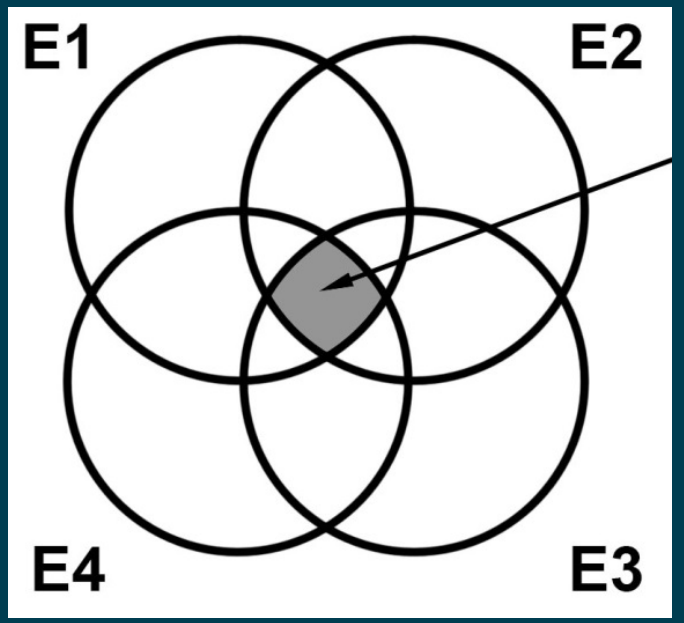
RIDM at Reclamation

RIDM process consists of:

1. Risk Analysis
2. Risk Assessment
3. Risk Management

Risk Analysis

- Risk analysis is the quantitative component of the RIDM process
- Philosophical basis for our risk analysis approach is the idea that a failure process can be conceptualized in the form of a narrative called a Potential Failure Mode (PFM)
- Mathematical basis is the multiplication rule of elementary probability theory, with probability of failure interpreted as the intersection probability of the *n* events of the PFM



Risk Analysis

- Typically performed in a facilitated team setting
- Participants represent various areas of technical expertise (including Consequences)
- Expert judgment is converted into subjective probability with the aid of verbal descriptors
- Basic product is a set of quantitative risk estimates
  - Annualized Failure Probability
  - Annualized Life Loss
- Added benefit is an improved understanding of the dam's strengths and weaknesses

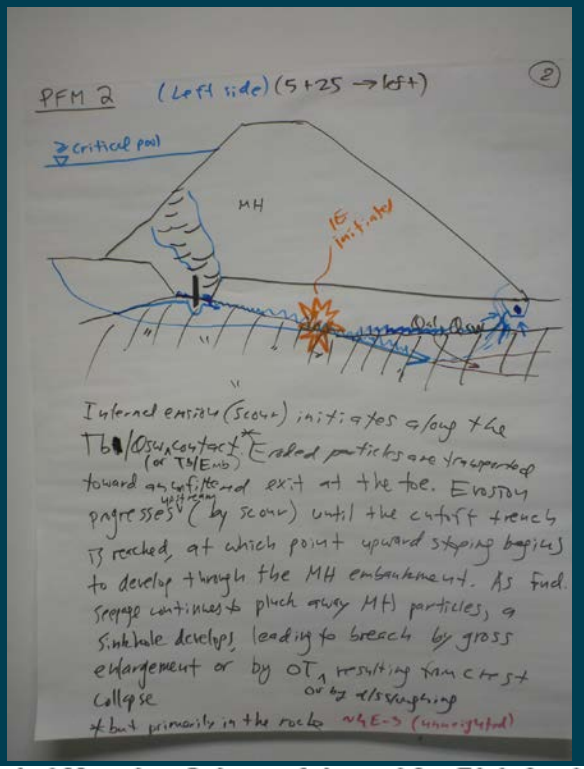
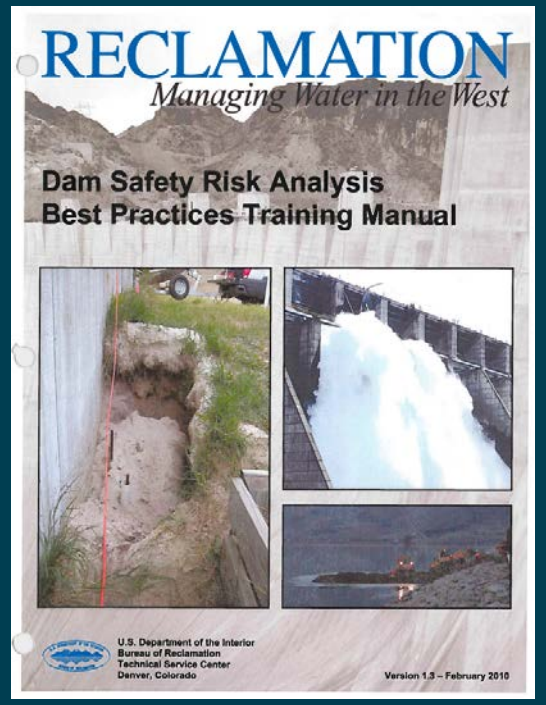


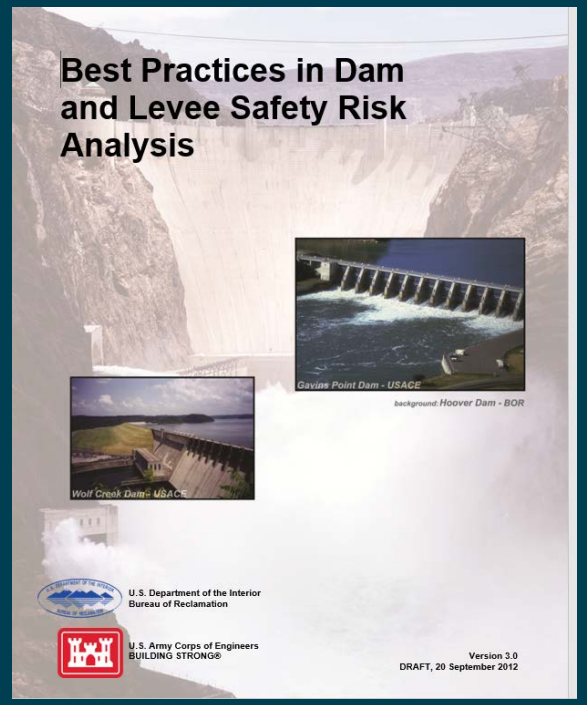
Table A-6-2.—Verbal Mapping Scheme Adopted for Risk Analysis

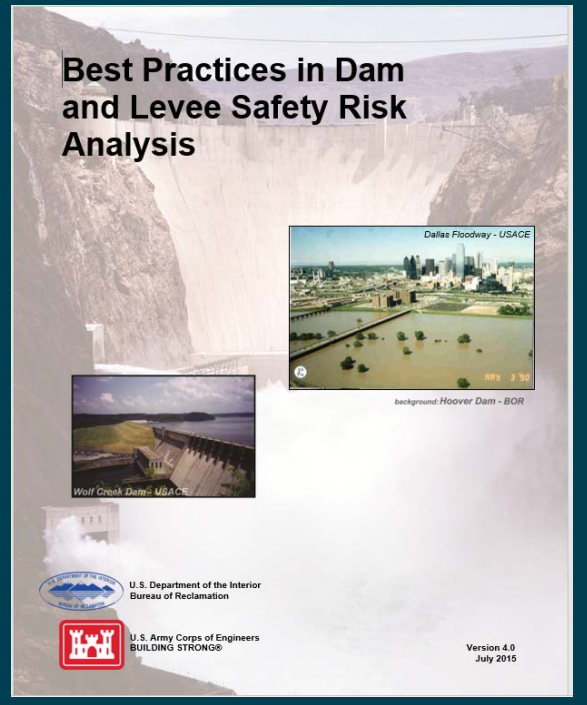
Descriptor	Assigned Probability
Virtually Certain	0.999
Very Likely	0.99
Likely	0.9
Neutral	0.5
Unlikely	0.1
Very Unlikely	0.01
Virtually Impossible	0.001

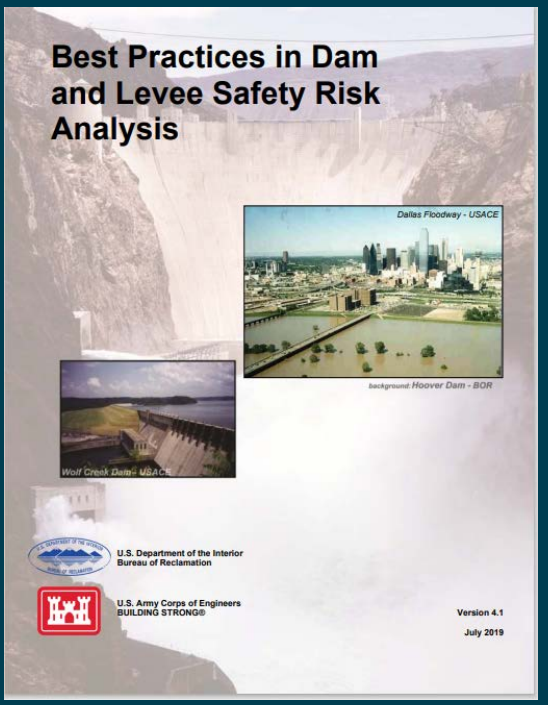
Risk Analysis

Best Practices









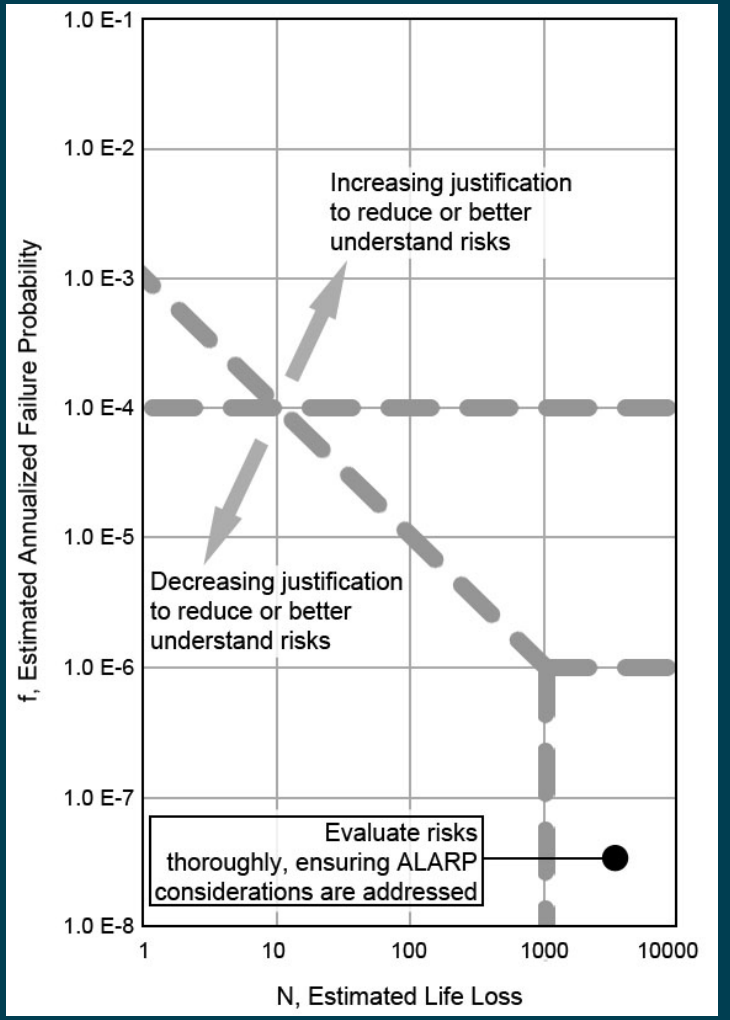
Risk Analysis

Best Practices

- Reviewed and updated periodically to stay current with state of practice, include new topics, incorporate lessons learned, and provide clarification where experience indicates it's needed.
- Guidance is not a prescriptive approach. Dam Safety risk analyses do not provide accurate or precise estimates.
- Numbers are less important than the identification, understanding, and documentation of the major risk contributors.

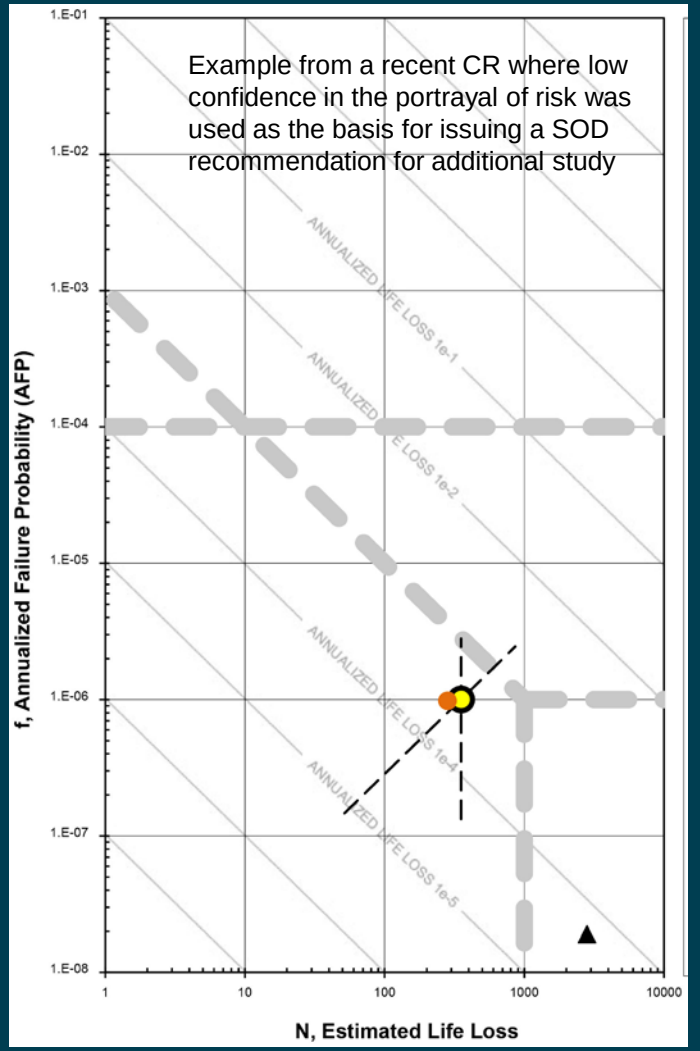
Risk Assessment

- The interpretation of the numbers
- Risks of each PFM are plotted on fN chart and compared to the visual guidelines
  - Total AFP is calculated as the probability of the union of the individual PFMs
  - Total ALL is the normalized “expected” life loss
- Basic objective of PPG is that our dams not significantly increase background risk of death
- When there is the potential for very high life loss, goal is for the risk of failure to be even lower



Risk Assessment

- Important to identify key risk driving PFMs, but also to consider the overall risk picture
- Uncertainty, and its potential impact on the portrayal or risk (confidence), are important
- Guidelines are not intended to serve as hard decision criteria (room for interpretation)
- Not attempting to model or “predict” failure, only to determine if there is a dam safety case to reduce or better understand the risk



Risk Assessment

- Risk analysis package: a report describing the results and a decision/summary document presenting the dam safety case
- Overall dam safety case goes beyond the risk estimates, and must reconcile them with design information, field data, performance observations, analysis results, and overall condition
- This takes experience, which is why key roles on dam safety projects are usually assigned to senior staff
- However, the team approach also provides a way for entry level staff to become involved and gain RIDM experience

Risk Management

- Risk management is the programmatic element of the RIDM process
- Risk analysis and assessment are typically performed by the Technical Service Center
- Risk management is the responsibility of the Dam Safety Office
  - A dedicated dam safety Program Manager is assigned to each of the five Regions
  - Track and prioritize the implementation of Safety of Dams (SOD) recommendations
  - Prepare budget estimates and requests

Region	Dam Name	Issue ID	Actual Status Date	Issue Description/Last Status
MP	BOCA	1984-SOD-B	Deleted:	Determine whether the riprap cover provides adequate upstream slope protection. Last Status: Upstream riprap appears to have performed satisfactorily, and remained in place during high reservoir winds/waves and flooding since 1984.
MP	BOCA	1996-SOD-A	Deleted:	Upgrade the seepage measurement installations by designing the toe drain measurement system to prevent backwater from interfering with measurements. Last Status: The Issue Evaluation Report of Findings, TM No. BO-8312-6, dated 2/29/2004, found this recommendation did not reduce risk imposed by the structure or improve understanding of key failure modes. Based on Decision Memo No. IE-Boca-2004-DP3 Boca Dam can continue to operate in normal fashion.
MP	BOCA	1998-SOD-A	Deleted:	Institute quantitative flow monitoring at the following locations (1) at the toe drain outfalls at the saddle dike, (2) at the wet area to the left of the spillway, (3) at the wet area at the right abutment groin, (4) at the right abutment drain, and (5) at the toe drain outfalls at the maximum section of the dam. Excavation to locate the toe drain outfalls at the saddle dike needs to be performed as part of this work. (Denver) Last Status: The Issue Evaluation Report of Findings, TM No. BO-8312-6, dated 2/29/2004, found this recommendation did not reduce risk imposed by the structure or improve understanding of key failure modes. Based on Decision Memo No. IE-Boca-2004-DP3 Boca Dam can continue to operate in normal fashion.
MP	BOCA	1998-SOD-B	Completed:	Install or scribe measurement points on the top of the parapet wall at 100-foot intervals, and also at any apparent low points, for the full length of the dam, and institute routine surveying of them. (Denver) Last Status: 5 additional deflection points were installed on the top center of the parapet wall and surveyed for baseline measurements on November 26, 2002. The baseline deflection measurement data was forwarded to the Denver instrumentation group (D-8460) on December 3, 2002 including a comment requesting revision of the L-23 for Boca Dam to reflect these additional 5 points.
MP	BOCA	1999-SOD-A	Completed:	Conduct a more detailed, comprehensive risk analysis to better define the expected loss of life and corresponding risks due to a failure of Boca Dam. Last Status: The Issue Evaluation Report of Findings, TM No. BO-8312-6, dated 2/29/2004, completed this recommendation. Based on Decision Memo No. IE-Boca-2004-DP3 Boca Dam can continue to operate in normal fashion.
MP	BOCA	2004-SOD-A	Completed:	Conduct additional analyses to better estimate the response of the dam to seismic loading and the consequences of dam failure. Upon completion, reassess the risk. Last Status: Per Issue Evaluation Decision Document dated 6/9/2006, Decision:Revise status of this recommendation to "Completed." The analysis completed indicates that significant deformations could occur as a result of foundation liquefaction, in the event of significant earthquake loading. Risk reevaluation of the seismic failure modes has been completed using available data. With this analysis, the probability of failure resulting from seismic loading was re-evaluated to be 2.7x10-5 and the annualized loss of life 4.7x10-3. Based on the risk, there may justification to implement risk reduction actions, however, additional data is needed to further confirm the need for risk reduction.
MP	BOCA	2005-SOD-A	Completed:	Perform a thorough investigation of the void in the right abutment of Boca Dam to determine the extent of the void. Last Status: Per CFR Decision Document dated 5/9/2007, Discussion: The status of this recommendation has been revised to "Completed." A void investigation report titled Boca Dam Void Investigation was transmitted from the Regional Engineer, Mid -Pacific Regional Office to the Dam Safety Office on June 14, 2005. Findings are that the void in question was a preconstruction exploration test pit that was poorly backfilled. That implies that other such test pits may also be poorly backfilled. That conclusion led to recommendation 2005-SOD-B to learn more about test pits that underlie the dam or are within the abutments.
MP	BOCA	2005-SOD-B	Completed:	Perform a thorough search of historical records to determine the method of excavation of the preconstruction test pits at Boca Dam, and develop an investigation program, if warranted by risk, for other test pits underlying the dam or located in its abutments. Last Status: Per Issue Evaluation Decision Document dated 6/9/2006, Decision:Revise status of this recommendation to "Completed." A search of historical records has been completed and the risk associated with preconstruction explorations does not warrant further action.
MP	BOCA	2006-SOD-A	Completed:	Conduct an exploration program to better define the properties and extents of the foundation alluvium. Re-analyze the risk with the results of the exploration program to determine if additional risk reduction actions are warranted. Last Status: Revise status of this recommendation to "Completed". This recommendation is considered complete with the finalization of the Issue Evaluation documentaton. The exploration program consisting of 16 Becker Penetration Test and 4 Becker Sample holes was completed in 2008. This data from that program was utilized in the reevaluation of the seismic risks at Boca Dam. The risk analysis determined that the total annual probability of failure resulting from seismic loading is 5.6 X 10-5 and the total annualized loss of life is 5.6 X 10-3.
MP	BOCA	2008-SOD-A	Completed: 12/22/2014	Conduct a Corrective Action Study to address risks to the embankment, foundation, and spillway under seismic loading. Last Status: Three alternatives for the main embankment and five alternatives for the spillway, and dike modification alternative were analyzed in the CAS to reduce the risks for seismic potential failure modes. A security enhanced technically preferred alternative was identified at the end of CAS. The security enhanced technically preferred alternative will be carried forward for final design and construction.
MP	BOCA	2014-SOD-A	Incomplete:	Perform final design and construction of the security enhanced technically preferred alternative identified in the corrective action study to reduce seismic risks at Boca Dam. Last Status: This recommendation is incomplete pending the completion of construction of the SOD modifications. Based on the results of the updated risk analysis for baseline, post-modification and reservoir restriction conditions for Boca Dam, the SOD modification with the security enhanced technically preferred alternative would result in an estimated post-modification total annualized life loss risk of 2.0x10 -4 , which is close to one order of magnitude below the threshold in the 2011 Interim Public Protection Guidelines.

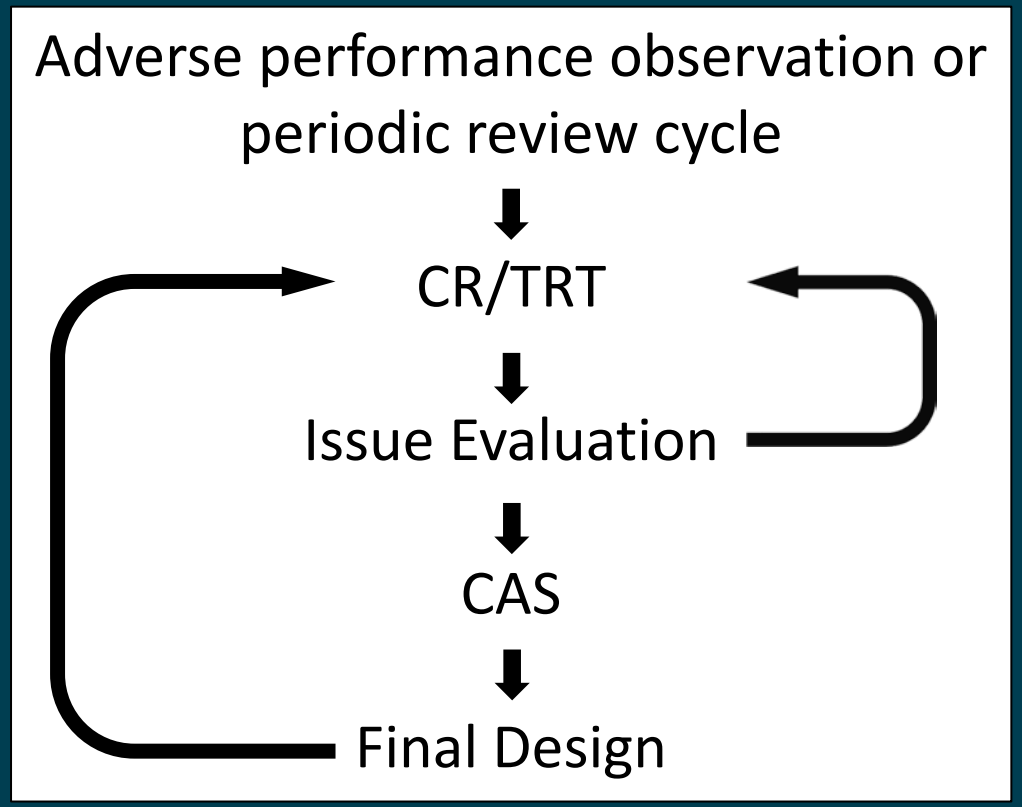
Risk Management

- Dam Safety recommendations must be prioritized
- Dam Safety Priority Rating (DSPR) system used to assess urgency based on factors such as condition of the dam, the controlling loading condition, the total estimated risk, and confidence
- The Dam Safety Office also has an internal prioritization scheme to help differentiate between dams in the same DSPR category

DSPR 1 – IMMEDIATE PRIORITY Immediate actions are necessary to reduce the risk of failure, including both interim actions and the implementation of long-term risk reduction alternatives.	Several of the following factors would typically apply at the DSPR 1 level: • There is direct evidence that a failure is in progress and that the dam could potentially fail if action is not taken quickly. • Risks are extremely high with respect to the applicable portion of the fN-chart guideline. • The high risk is driven by a potential failure mode manifesting under normal operating conditions. • The failure mechanism of concern has been observed in practice and/or the dam is in poor condition. • Confidence in the portrayal of risk is high.
DSPR 2 – URGENT PRIORITY Expedited actions are likely needed to reduce the risk of failure, including the implementation of long-term risk reduction alternatives and serious consideration of interim actions.	Several of the following factors would typically apply at the DSPR 2 level: • Risks are very high with respect to the applicable portion of the fN-chart guideline. • While there may be evidence that a PFM has initiated, there is no direct evidence of advanced progression or a failure in progress. • The high risk is driven by a potential failure mode associated with a relatively frequent (per the interpretation of the team) loading condition. • The risk is driven by a single potential failure mode, but the residual risk (collective risk of the remaining potential failure modes) is also relatively high. • Although the estimated risk is very high, the overall condition of the dam is good, the performance is relatively well understood (and not expected to deteriorate under the loading conditions anticipated in the near future), and most of the DSPR 1 considerations above would not realistically apply. • Confidence in the portrayal of risk is high.
DSPR 3 – HIGH PRIORITY The identified dam safety deficiencies are a concern, and interim action may need to be considered while ways of addressing the long-term risks are being evaluated.	Several of the following factors would typically apply at the DSPR 3 level: • The risks are relatively high with respect to the applicable portion of the fN-chart guideline. • The high risk is driven by a potential failure mode(s) associated with a relatively remote loading condition. • The high risk is driven by a potential failure mode(s) associated with a normal operating condition or relatively frequent loading, but there is no clear or direct evidence of a PFM in progress. • Confidence in the portrayal of risk is moderate to high.
DSPR 4 – MODERATE PRIORITY The risks as portrayed indicate a potential concern, but interim action beyond routine monitoring may not be needed to effectively manage them.	Several of the following factors would typically apply at the DSPR 4 level: • The plotting position of the total risk marker places it near the applicable portion of the fN chart guideline, but there are multiple PFMs contributing to the plotting position. • The estimated risks are relatively high with respect to the applicable portion of the fN-chart guideline, but with low or low to moderate confidence in the portrayal of risk. • The estimated risks are relatively low and confidence in the portrayal of risk is high or moderate to high, but most of the DSPR 5 considerations below would not realistically apply. • The dam is in good condition and has performed well to date. • The response of the dam to reservoir loading is predictable, and conditions do not appear to be changing.
DSPR 5 – LOW PRIORITY The potential failure modes identified at the facility do not present a significant concern, and risks can be effectively managed via routine monitoring.	Several of the following factors would typically apply at the DSPR 5 level: • The risks are relatively low with respect to the applicable portion of the fN-chart guideline. • The seismic and hydrologic loadings are reasonably up to date. • The design of the dam is considered state-of-the-art, or the dam has been recently modified to address any previously identified dam safety issues. • Confidence in the portrayal of risk is high.

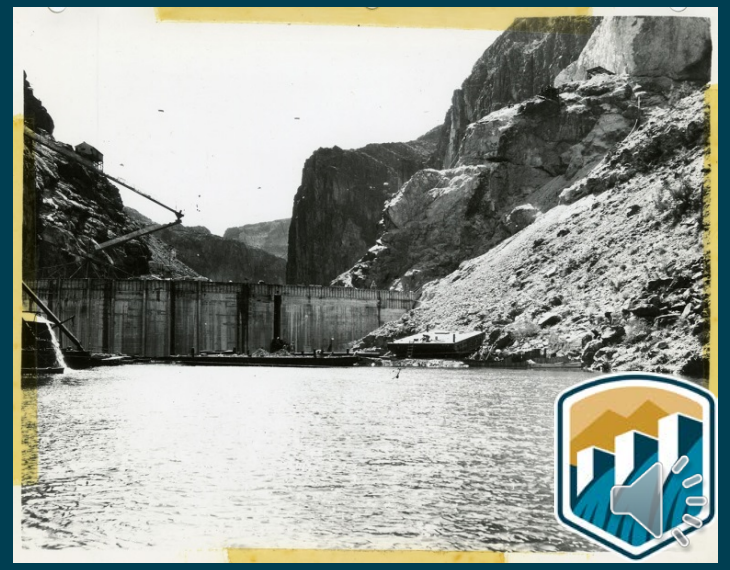
Risk Management

- Comprehensive Reviews (CRs) are performed on an 8-year cycle
- Periodic Facility Reviews (PFRs) are performed between CRs
  - Supported by the Technical Response Team (TRT), basically the CR team
- Annual Site Inspections (ASIs) are performed once a year
- Monthly (or more frequent) visual and instrumentation monitoring



Overview of Reclamation's inventory of dams

- Reclamation has 367 high/significant hazard dams spread over 243 facilities
- About half of these dams were built before 1950
- State of the practice and understanding of potential loading conditions (e.g., flood and seismic) have changed since many of these dams were built
- Changes in downstream populations have occurred
- Dam Safety program was established to ensure our dams do not present an unreasonable risk



Overview of Dam Safety Program

- Current focus of the program is on conditions that could lead to a life-threatening, uncontrolled release of water
- Key Developments:
  - Numerous dam failures in the 1970s (non-Reclamation)
  - 1976 failure of Teton Dam
  - 1978 Reclamation Safety of Dams Act
  - 1979 Federal Guidelines for Dam Safety (last updated in 2015)
  - 1997 Public Protection Guidelines (updated 2011 and 2022 update under review)

Track record

- Risk informed decision making process began to be implemented in the 1990s
- Since that time, there have been
  - Three-plus CR cycles for each facility (over 1000 CR-level quantitative risk analyses)
  - Over 230 Issue Evaluation-level risk analyses
  - Over 120 CAS-level risk analyses
- About 100 modifications have been (or are being) performed under the authority of the Reclamation Safety of Dams Act

Track record

- First set of dams modified under the Act had objective performance concerns or did not meet deterministic hydrologic design criteria
  - 1980s, typical of pre-RIDM approach
- Second set of mods (1990s) was evenly split between dams with static, seismic, and hydrologic issues
- Third set of mods (since 2000) is dominated by dams with internal erosion related concerns
- The RIDM process has been particularly helpful in evaluating the significance of threats for which there are no deterministic safety criteria, such as those associated with excessive seepage

Example: Modification of Hyatt Dam, Oregon

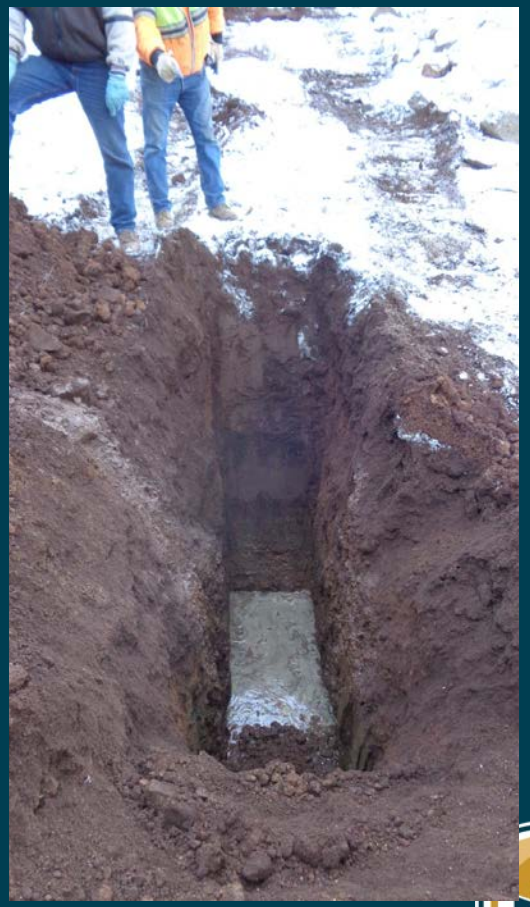
- Small embankment dam constructed in 1922 by the local irrigation district (title eventually transferred to Reclamation)
- Generally constructed as a homogeneous rolled earth embankment
  - Some use of puddled fill
- Design included a concrete-pipe toe drain surrounded by “loose rock”
- Design included a small cast-in-place core wall along the base of the cutoff trench

Example: Modification of Hyatt Dam, Oregon

- No adverse performance observations were reported over the first 50 years
- Seepage along the left abutment began to be observed in the 1970s
- Toe drain flows dropped abruptly in 2009, with new seepage areas subsequently reported
- An inspection was performed and revealed that the toe drain pipe was damaged and deteriorated in some places

Example: Modification of Hyatt Dam, Oregon

- The standards-based solution at this point would have been to replace the toe drain
- However, based on low confidence in its interpretation of the overall risk, the 2009 CR team recommended an Issue Evaluation study
- The Issue Evaluation was focused on data collection to reduce the uncertainty of the risk estimates, including geotechnical investigations of the embankment and foundation

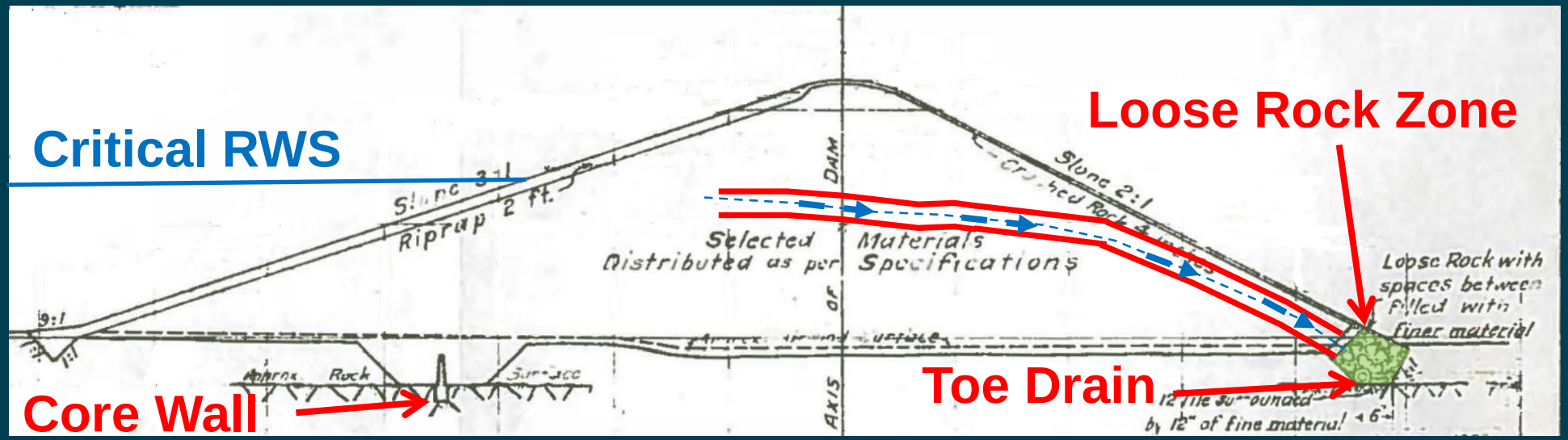


Example: Modification of Hyatt Dam, Oregon

- The investigations revealed wet seams in the embankment as well as fractured rock in contact with the overburden beneath the downstream shell
- The elevations of these features corresponded to reservoir water surface (RWS) elevations where seepage changes occurred
- The Issue Evaluation risk team concluded that while the damaged toe drain was a contributor, the risks of the key PFMs would remain high if the toe drain was simply replaced

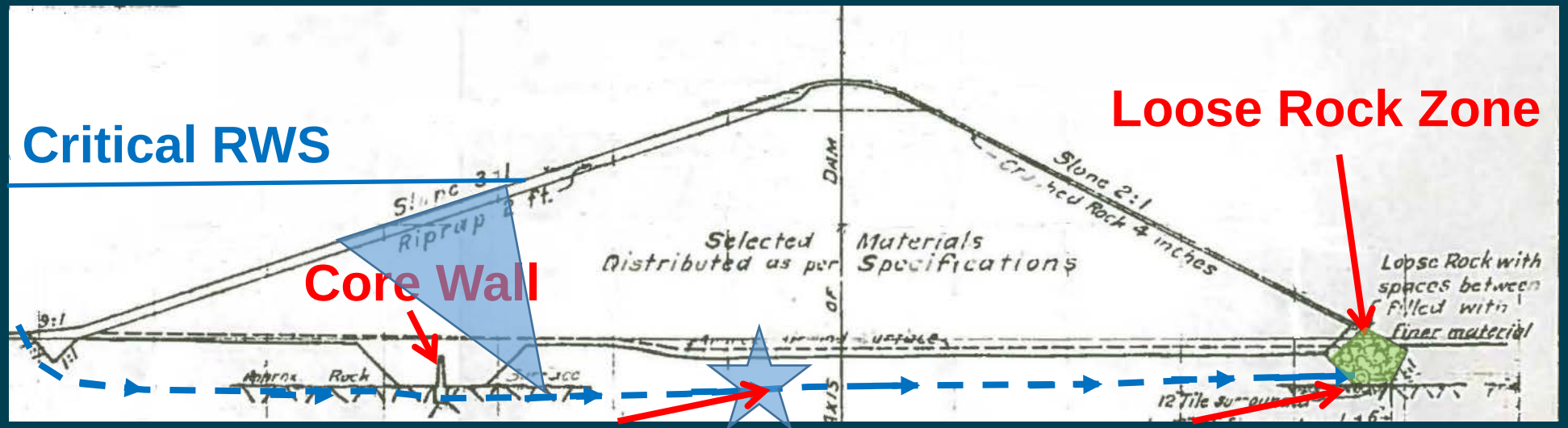
Example: Modification of Hyatt Dam, Oregon

- Controlling PFM 1: Internal erosion of the embankment (by backward erosion piping)



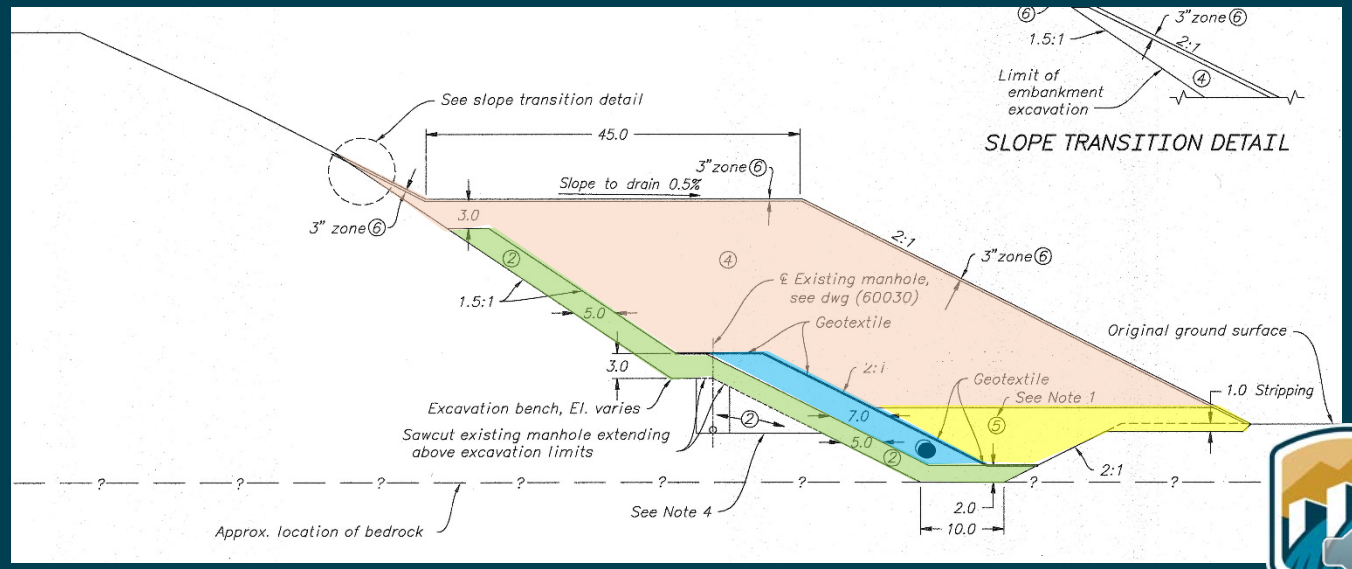
Example: Modification of Hyatt Dam, Oregon

- Controlling PFM 2: Internal erosion of the foundation along the contact between the rock and the overburden (by scour)



Example: Modification of Hyatt Dam, Oregon

- The Issue Evaluation indicated a relatively high risk of failure, with relatively high confidence in the overall portrayal of risk
- Recommendation was made to proceed into a corrective action study
- Dam was modified in 2017 to reduce the risk of internal erosion



RIDM and the Dam Safety Program

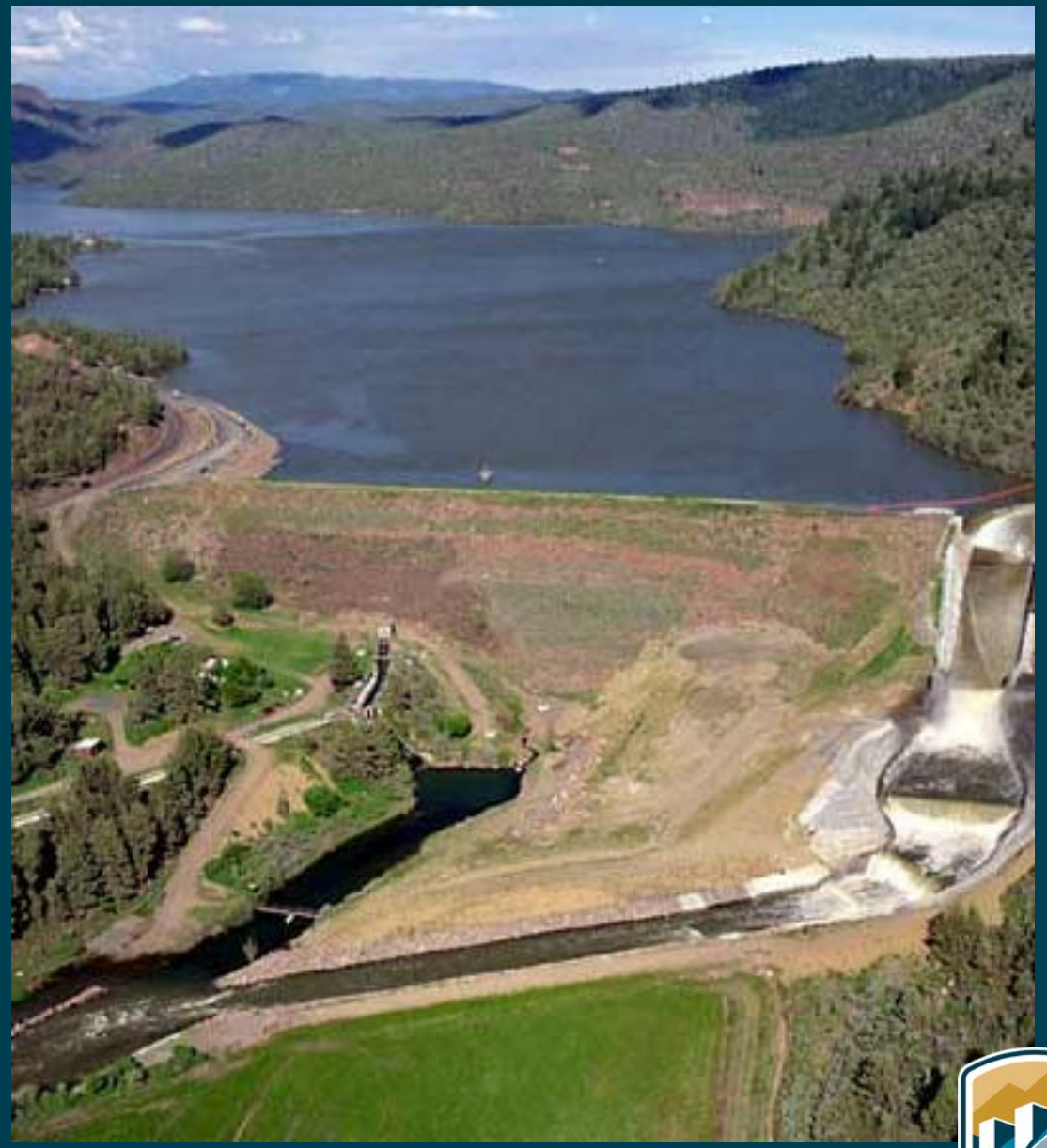
- Limited funding for dam safety work, must be approved by Congress
  - The budget for the Dam Safety Program represents only a percentage of Reclamation's overall operating budget
- We believe that the use of the RIDM process has resulted in limited dam safety funding being spent in a way that maximizes its impact
  - Don't spend it on non-dam safety issues
  - Address the most urgent issues first

Incorporating RIDM into a new dam safety program

- RIDM allows for a systematic way of prioritizing resources
- A key benefit of doing a risk analysis is that it helps improve a team's overall understanding of the dam's strengths and weaknesses
- However, the numbers generated in a risk analysis would be difficult to interpret in the absence of public protection guidelines
- Before introducing RIDM into a new dam safety program, it would be necessary to establish a similar set of guidelines
- Reclamation's PPG were developed specifically for the social, political and regulatory environment of the jurisdiction in which we operate. They may not be applicable to other jurisdictions

Future Challenges

- Reclamation is in the process of updating its Public Protection Guidelines
  - RIDM process continues to evolve
- Some of the topics on which new guidance is being prepared include:
  - Risk-informed design
  - Construction risk
  - Incident risk



Risk Informed Design

- Modifications to Reclamation dams are performed for a variety of reasons other than high estimated risk.
- Modifications can also involve increasing storage capacity or hydropower development. In these cases, Reclamation dams must be risk neutral (no net increase to the baseline risk).
- Regardless of who is designing the modification, Reclamation's design standards are considered, however; meeting the letter and spirit of the design standards does not in itself assure a risk neutral modification – risk analysis usually required before approval

Construction Risk

- Reasons why risk exposure might be different during construction:
  - Modification involves a temporary reduction in the minimum crest elevation, reduction in the spillway or outlet capacity, or excavation at the toe of the dam
- Risk management options:
  - Impose a temporary reservoir restriction
  - Schedule construction to minimize the time of critical excavation work
  - Updating the emergency Action Plan (EAP)
  - Select alternative with a relatively low construction risk

Incident Risk

- The February 2017 spillway incident at Oroville Dam (CA DWR) has had repercussions throughout the industry
- Although the incident did not involve a breach, there were major downstream impacts
- This had led to questions about what kinds of events should fall under the purview of a dam safety program

Incident Risk

- In the future, incident threats that are highly visible and with the potential to result in public disruption may fall under the Dam Safety Program
- However, since such incidents are not necessarily associated with a risk of life loss, so difficult to use the existing PPG to evaluate
  - Goal of the PPG is that our dams not increase the background risk of death for those downstream

Conclusions

- Our use of the RIDM process results in limited dam safety funding being spent in a way that maximizes its impact
- Our risk analysis methodology is philosophically transparent and mathematically simple
- RIDM process must continue to evolve in order to remain relevant
- A key challenge we face is ensuring that any changes we make to PPG are value added
- Proposed new guidance on incident risk will help both risk estimators and decision makers adapt to changing views on the role of our dam safety program


Thank you for your time and interest!
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