

FERC
Risk-Informed Decision Making Guidelines

Chapter 2

Risk Analysis

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ACRONYMS

AEP	annual exceedance probability
ALARP	as-low-as-reasonably-practicable
BOR	U.S. Department of the Interior, Bureau of Reclamation
CSSL	cost to save a statistical life
D2SI	Division of Dam Safety and Inspections (FERC)
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
PAR	population at risk
PDF	probability density function
PFM	potential failure mode
PFMA	potential failure mode analysis
QRA	quantitative risk analysis
RIDM	risk-informed decision making
RRB	risk review board
SLPRA	screening level portfolio risk analysis
SME	subject matter expert
SQRA	semi-quantitative risk analysis
SSHAC	senior seismic hazard analysis committee
USACE	U.S. Army Corps of Engineers
VSL	value of statistical life
WTP	willingness to pay to prevent a statistical fatality

CHAPTER 2 RISK ANALYSIS

2.1 INTRODUCTION

2.1.1 General

The Federal Energy Regulatory Commission (FERC) Division of Dam Safety and Inspections (D2SI) is responsible for the development, dissemination, and interpretation of methodology guidance for use in conducting dam safety risk analyses. This document does not try to describe in detail how to analyze risks. It only describes the general practices used by those who analyze risks. The current state-of-the-practice for analyzing dam safety risks is presented in the *Best Practices in Dam and Levee Safety Risk Analysis*, a document developed by the Bureau of Reclamation (BOR) and the U.S. Army Corps of Engineers (USACE) for the purpose of summarizing the overall philosophy, methods, and approach to risk analysis for dam safety (BOR/USACE, 2015).

2.1.2 Definition

As defined by the International Commission on Large Dams (ICOLD), risk analysis is “the use of available information to estimate the risk to individuals or populations, property or the environment, from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification, and risk estimation.” (ICOLD, 2005).

The risk analysis process involves the scientific characterization of what is known and what is uncertain about the present and future performance of the dam system under examination (ICOLD, 2005). It is a structured process aimed at estimating both the probability of failure of the dam or dam components and the consequences of failure (often, though not always, restricted to those consequences resulting from uncontrolled release of the reservoir).

Risk analysis is the first component of risk management, as shown on Figure 2-1 (FEMA, 2015). It is the portion of the process in which the site-specific potential failure modes, structural performance, and adverse consequences are identified. It is also the process during which a quantitative or qualitative estimate of the likelihood of occurrence and magnitude of consequence of these potential events is made. A critical first step in a risk analysis is identifying the site-specific potential failure modes at a given dam. The frequency of occurrence of the loadings (e.g., reservoir load levels, floods, earthquakes, ice loading, etc.) that could initiate potential failure and then cause adverse consequences is estimated and considered as part of a risk analysis.

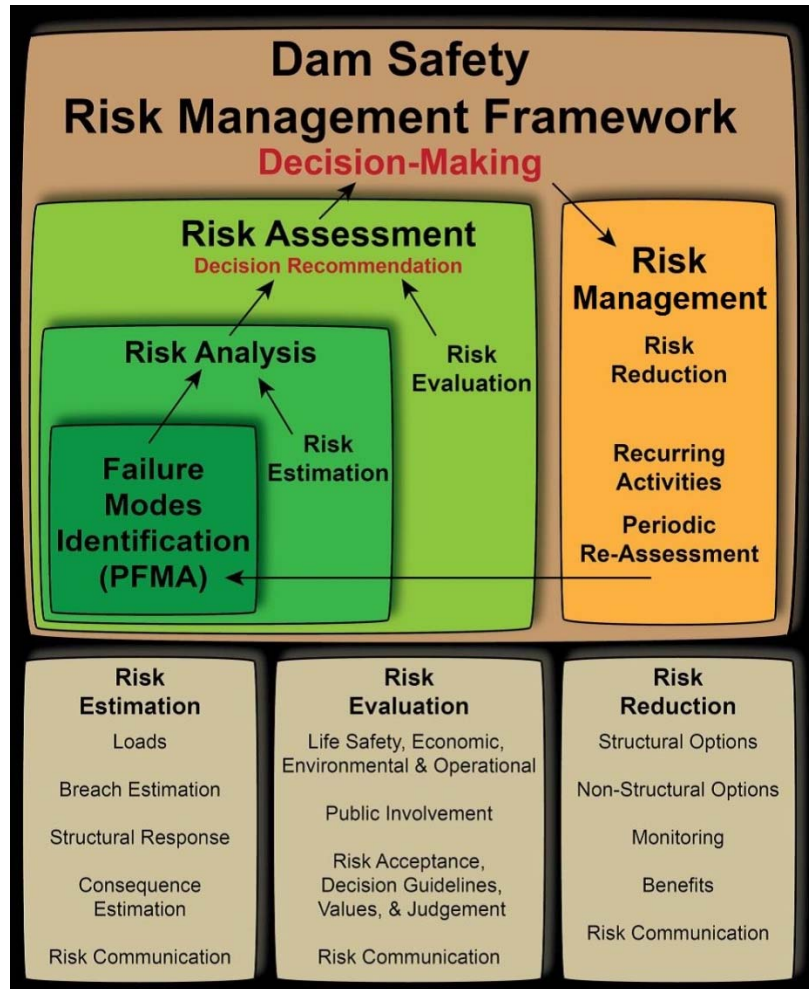


Figure 2-1. Relationship between Risk Analysis, Risk Assessment, and Risk Management (revised from FEMA, 2015)

2.1.3 General Description

Risk analyses can provide valuable input to decisions made at various stages of a project and serve other important purposes. Risk analysis is a tool that can assist and provide important insights to the decision making process for a single dam or within an inventory of dams. Thus, several types of risk analyses can be used as described in Section 2.3. Risk analysis can be quantitative (i.e., the outputs and inputs are numeric) or qualitative.

The first step common to all types of risk analyses is the identification of site-specific potential failure modes. (See Chapter 14 of the FERC Engineering Guidelines for the Evaluation of Hydropower Projects for a description of the Potential Failure Mode Analysis (PFMA) process). For a given dam or project, all of the relevant types of loadings that may be experienced should be considered when identifying potential failure modes. Risk analyses should consider the interactions between individual potential failure modes in order to properly understand the overall risk and how that risk can be

reduced. The decision framework for a particular structure considers the rolled up risk across all potential failure modes, which may not be a simple sum of the risk for each potential failure mode considered individually.

2.1.4 Considerations

The event of interest in a dam safety risk analysis is dam failure which is defined as a set of events leading to sudden, rapid, and uncontrolled release of the reservoir impoundment (USACE, 2014). Further, it is recognized that there are lesser degrees of failure and that any malfunction or abnormality outside the design assumptions and parameters that adversely affect a dam's primary function of impounding water could be considered a failure (FEMA, 2015). The probability of exceeding an analytical limit state (i.e. factor of safety less than one) is not the same as probability of failure. Limit state exceedance is only one factor to consider and may not necessarily initiate failure of a potential failure mode. Similarly, the probability of a serious incident is not the same as probability of failure.

Individual dams are often part of larger infrastructure systems. Within these watershed systems, risk is attributed to the specific infrastructure that is the source of the risk. This includes due consideration for cascading impacts in the 'downstream' direction. If failure or non-failure of the dam being assessed would result in overtopping and subsequent breach of downstream dams and/or levees, then the risk associated with these cascading failures would be attributed back as a consequence to the dam being assessed. Risks generated by failures of 'upstream' infrastructure are usually not considered at the downstream dam being assessed. If failure of an upstream dam would result in overtopping and breach of the dam being assessed, then increases in the magnitude and frequency of loading caused by failure of the upstream dam would not be included in the risk estimate.

To support inventory prioritization decisions or to communicate the flood risk from multiple flooding sources, there may be a benefit in estimating the risk from a systems perspective in certain situations. These analyses can support improved prioritization decisions within the larger watershed to obtain more efficient and effective risk reduction across the inventory. In these special cases, it may be appropriate to evaluate the cascading impacts of failure in both the 'upstream' and 'downstream' directions.

The risk analysis results will be reviewed, scrutinized, and debated. The risk analyst or team must be prepared to explain and defend the logic behind the risk estimate. This process leads to better decisions in an environment of imperfect information. A group of experts will rarely agree on all of the details of a risk analysis but can usually obtain agreement on the key decisions and the path forward. This agreement is achieved by working for consistency between the risk estimate, recommended actions, and understanding of the situation (i.e. does it make sense?).

2.2 TYPES OF RISK AND RISK MEASURES

2.2.1 Types of Risk

In the dam safety context there are several different types of risk that can be identified and estimated. One way to think of these ‘types of risk’ is to first understand under what conditions water being held by the dam might flow downstream and inundate the downstream area. These conditions are called inundation scenarios (USACE, 2014). The risk associated with a dam can be thought of in terms of four inundation scenarios shown in Figure 2-2. These include:

- breach prior to overtopping
- overtopping with breach
- inundation resulting from partial or complete release of the reservoir due to the malfunction of dam components or misoperation
- spillway flow without breach of the dam or overtopping without breach (non-breach)

For the fourth inundation scenario, “spillway flow” means the controlled release of water through the outlet works or spillway up to and including full outlet works or spillway discharge.

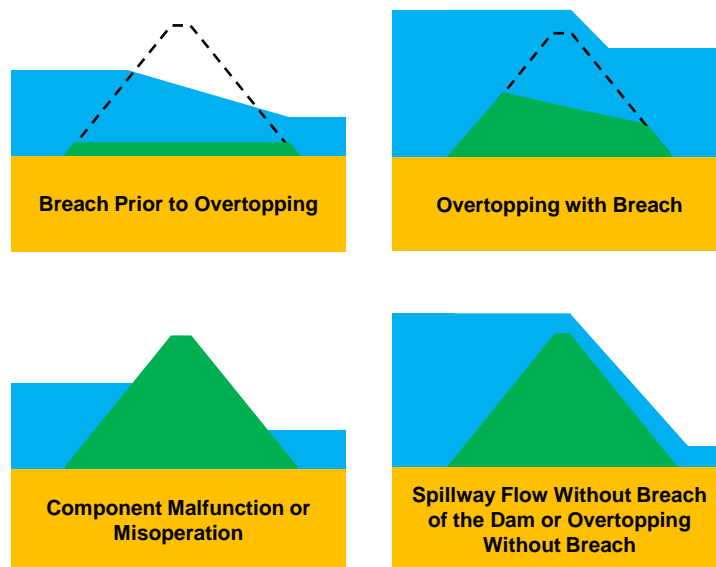


Figure 2-2. The Four Inundation Scenarios (from USACE, 2014)

From these four different inundation scenarios, three different types of risk can be estimated. These types of risk include incremental risk, non-breach risk, and residual

risk. Each of these types of risk focus on a different aspect of risk and are described in the following sections.

2.2.1.1 Incremental Risk

The ‘incremental risk’ is the risk (likelihood and consequences) to the reservoir area and downstream floodplain occupants that can be attributed to the presence of the dam should the dam breach prior or subsequent to overtopping, or undergo component malfunction or misoperation, where the consequences considered are over and above those that would occur without dam breach (USACE, 2014). Commonly incremental risk is the term most often considered when one uses the generic term, ‘risk’. The consequences typically are due to downstream inundation, but loss of the reservoir can result in significant consequences upstream of the dam as well.

The incremental consequences are a component of incremental risk and are defined as follows:

Incremental consequences	=	Consequences associated with the estimated performance of the project with breach, component malfunction, or misoperation	-	Consequences associated with the estimated performance of the project without breach, component malfunction, or misoperation
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This definition, when applied to flood-induced breach, is such that incremental consequences for a particular inflow flood magnitude is the difference between the consequences of a dam breach and the consequences of a non-breach at the inflow flood magnitude.

An important principle of reservoir operations is that a dam is not to be operated at any time in such a way that the downstream flood severity is greater than it would have been had the dam not been constructed. This principle will be reflected when assessing and evaluating the risk associated with the non-breach inundation scenario.

2.2.1.2 Non-Breach Risk

Even if the dam functions as intended and the dam does not fail, the reservoir area and the downstream affected floodplains may be in a state of high risk. This risk in the reservoir area and affected downstream floodplains is due to ‘normal’ operation of the dam (e.g. large spillway flows within the design capacity that exceed channel capacity) or ‘overtopping of dams without breach’ scenarios. This is referred to as the ‘non-breach’

risk (USACE, 2014). The non-breach risk is essentially the risk that exists even if the infrastructure performs its intended function without failing.

Most of the information needed to estimate the risk for non-breach scenarios is readily available from the information gathered to perform a risk analysis to estimate the incremental risk.

2.2.1.3 Residual Risk

The risk in the reservoir area and downstream of the dam at any point in time (i.e., prior to, during, or after implementation of risk reduction measures) is referred to as ‘residual risk’, i.e. the risk that remains (USACE, 2014). The residual risk associated with a dam consists of two components as shown in Figure 2-3. It should be noted that the value of residual risk is the same as the incremental risk for scenarios where there are no non-breach risks (e.g. normal operation potential failure modes with spillway or outlet works flows that do not exceed safe channel capacity.) Understanding the two components that comprise residual risk is important.

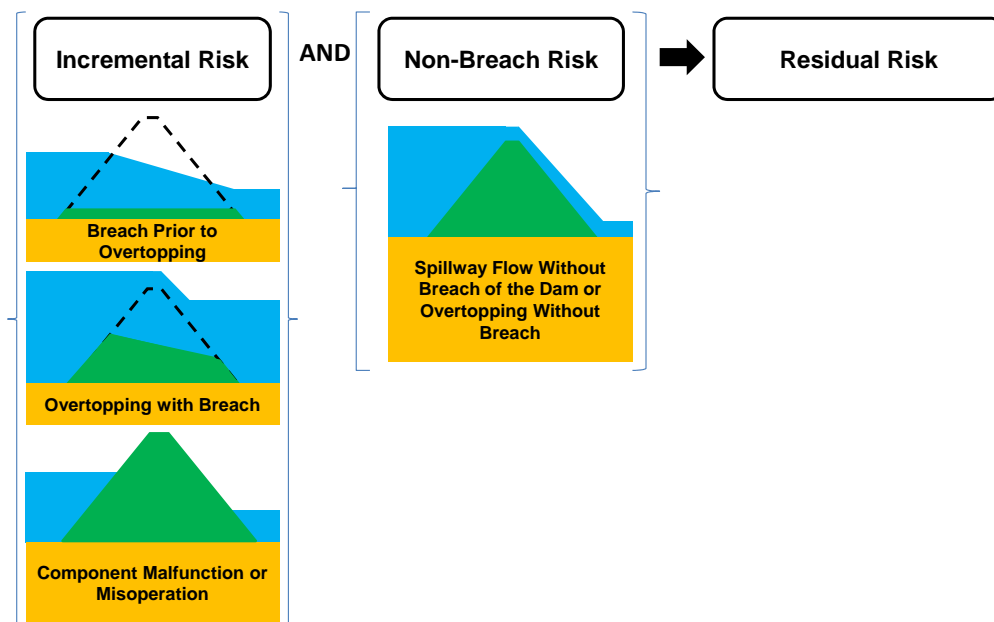


Figure 2-3. Residual Risk (from USACE, 2014)

2.2.2 Risk Measures

Four types of risk measures are to be estimated and provided¹:

1. Life safety risk – which includes incremental and non-breach risk.

¹ See Section 2.3 for listing of risk measures to be provided for each level of risk analysis.

2. Annual probability of failure (APF).
3. Economic considerations – which includes incremental and non-breach consequences.
4. Environment and other non-monetary consequences - which includes incremental and non-breach consequences.

Each of these risk measures is discussed in the sections below.

2.2.3 Life Safety

Three types of incremental life safety risk are to be evaluated:

1. Individual incremental life safety risk using probability of life loss for the identifiable person or group by location that is most at risk of loss of life due to dam breach.
2. Societal incremental life safety risk expressed in two different ways:
 - a. Probability distribution of potential life loss.
 - b. Average annual life loss (AALL).

It is important that the contributions from all individual potential failure modes, loading types, loading ranges, exposure conditions, subpopulations at risk, etc., are analyzed and accounted for. This analysis and evaluation of each individual potential failure mode can lead to an improved understanding of the potential failure modes and the exposure conditions that most affect the incremental life safety risk. It can also provide insights that can lead to the identification of both structural and non-structural risk reduction measures, including interim risk reduction measures.

Non-breach life safety risks will also be considered.

2.2.3.1 Individual Incremental Life Safety

The individual incremental life safety risk is represented by the probability of life loss for the identifiable person or group by location that is most at risk of loss of life due to dam breach. This is computed from all exposure conditions and all potential failure modes associated with all loading or initiating events, with due regard for non-mutually exclusive potential failure modes.

Individual incremental life safety risk should be checked below the main and each auxiliary structure (e.g., dike, saddle dam, etc.) to verify that the person or group, which is most at risk, has been properly identified.

2.2.3.2 Societal Incremental Life Safety

2.2.3.2.1 Probability Distribution of Potential Incremental Life Loss. This societal incremental life safety risk is represented by a probability distribution of the estimated annual probability of potential life loss from dam failure or breach, for all loading types and conditions and all potential failure modes and all population exposure scenarios. This is displayed as an F-N chart which is a plot of the cumulative frequency² of incremental life loss of N or more lives (F) vs. incremental loss of life (N) associated with the incremental flood risk, as shown on Figure 3-3 in Chapter 3.

2.2.3.2.2 Average Annual Life Loss (AALL). The value of this metric for a dam should be estimated from all potential failure modes associated with all loading or initiating event types and considering all exposure conditions associated with life loss. AALL is displayed in an f-N chart as shown on Figure 3-4 in Chapter 3. The estimated life loss plotted on the horizontal scale is the weighted average incremental life loss (\bar{N}). This value is averaged over all flood and earthquake loading magnitudes, all potential failure modes and all exposure conditions (e.g. day and night) that are considered in the risk analysis. The average value tends to be closer to the life loss estimated for those potential failure modes that are most likely to occur. Simply put, \bar{N} is the weighted average life loss per failure and can be computed as AALL/APF.

2.2.3.3 Non-Breach Life Safety

The life safety risk associated with the non-breach inundation scenario is to be assessed, communicated, and considered in guiding actions. The non-breach life safety risk is to be plotted on the cumulative frequency distribution of potential life loss (F-N) chart with the x-axis showing Life Loss, N, from non-breach flood, as shown on Figure 3-5 in Chapter 3.

2.2.4 Annual Probability of Failure (APF)

Annual probability of failure (APF) will be estimated for those potential failure modes associated with the incremental risk. Annual probability of failure will be estimated from all potential failure modes associated with all loading or initiating event types. Although

² In probability textbooks a cumulative (probability) distribution function (CDF) is defined to have probability “less than or equal to” on the vertical axis and a complementary cumulative (probability) distribution function (CCDF) is defined to have probability “greater than” on the vertical axis. Although similar to a CCDF, an F-N chart is subtly, but in some cases importantly, different because it has probability “greater than or equal to” on the vertical axis rather than “greater than” as in the CCDF.

only the combined annual probability of failure of all potential failure modes is to be evaluated against this guideline, it is important that the contributions to the APF from the individual potential failure modes, loading types, loading ranges, exposure scenarios, etc., are analyzed. The analysis and evaluation of the individual potential failure modes can lead to an improved understanding of the potential failure modes that affect the combined annual probability of failure of the dam. It can also provide insights that can lead to the identification of both structural and non-structural risk reduction measures, including interim measures.

2.2.5 Economic Considerations

Economic considerations include both the direct losses of the failure of a dam and other economic impacts on the regional or national economy (USACE, 2014).

Direct losses include the damage to property located downstream from the dam due to dam failure. These include damage to private and public buildings, contents of buildings, vehicles, public infrastructure such as roads and bridges, public utility infrastructure, agricultural crops, agricultural capital, and erosion losses to land. The sudden loss of the reservoir due to a dam failure could result in losses to property and infrastructure within the reservoir area (upstream of the dam). Direct losses also include the value from the loss in services provided by the dam such as hydropower (incremental cost to replace lost power), water supply (municipal, industrial, irrigation), flood damage reduction, navigation (incremental cost for alternate transportation, if available), and recreation.

Another category of direct losses are the costs associated with the emergency response for evacuation and rescue and the additional travel costs associated with closures of roads and bridges. These losses are commonly included in computing direct economic loss due to dam failure.

Another potential direct loss is the cost of repairing the damage to the dam. This is a complicated issue and to some degree depends on the extent of damage to the dam. If the dam can be repaired, these repair costs may or may not be counted as a direct economic cost (loss). In the case of catastrophic failure, these rebuilding costs are typically not included in the direct costs, as the decision to rebuild the dam depends on the post-failure benefits (which the dam owner would have to evaluate separately) (USACE, 2014).

Indirect economic impacts are those associated with the destruction of property and the displacement of people due to the failure. The destruction due to the failure flood can have significant impacts on the local and regional economy as businesses at least temporarily close resulting in loss of employment and income. Similarly, economic activity linked to the services provided by the dam will also have consequences. These would include economic impacts on business that provide goods and services for the recreation activities associated with the reservoir. All these indirect losses then have

ripple or multiplier effects in the rest of the regional and national economy due to the resulting reduction in spending on goods and services in the region. In this way, a dam failure can have widespread economic losses throughout the region. These losses are the increment to losses above those that would have occurred had the dam not failed. These are often difficult to estimate or substantiate.

In addition to these economic considerations, the dam owner should consider the financial losses (dam owners' corporate business losses) and impacts from a dam failure. These financial losses might include both direct and indirect impacts.

It is strongly recommended that the analysis of economic considerations be performed by qualified economists.

2.2.6 Environmental and Other Non-Monetary Consequences

A dam failure has both direct and indirect consequences that cannot be measured in monetary terms (USACE, 2014). These stem from the impacts of the failure flood and loss of reservoir on environmental, cultural, and historic resources. In most cases, the assessment of the impacts of dam failure will be the reporting of area and type of habitat impacted, habitat of threatened and endangered species impacted, number and type of historic sites impacted, and the number and type of culturally significant areas impacted.

An additional indirect non-monetary consequence could be the exposure of people and the ecosystem to hazardous and toxic material released from landfills, warehouses, and other facilities. An estimate of the locations and quantities should be compiled identifying where significant quantities are concentrated. A potential additional source of hazardous and toxic material is the sediment accumulated behind the dam. Identifying and enumerating these indirect hazards could be important enough to require additional consequence studies including estimating additional fatalities due to exposure to these hazards. Although these non-monetary consequences may not provide the sole basis for risk reduction, they can provide additional information for decision making. They can also be used to identify risks to be managed separately from dam modifications.

Intangible consequences are those that have no directly observable physical dimensions but exist in the minds, individually and collectively, of those affected. Such consequences are real and can support decisions. Intangible consequences can include such things as (ANCOLD, 2003):

- The grief and loss suffered by relatives and friends of those who die;
- The impact of multiple deaths on the psyche of the community in which they lived;

- The stress involved in arranging alternative accommodations and income;
- The sense of loss by those who enjoyed the natural landscape destroyed; and
- The fear of lost status and reputation of the dam owning/regulating organization(s) and their technical staff.

The effect of these intangible consequences can be observed more noticeably in terms of increased mental health expenditures and increased suicides.

2.3 LEVELS OF RISK ANALYSES

2.3.1 General

Risk analyses can be performed for a number of different purposes using a variety of information. The level of detail (and rigor) included in a risk analysis should depend on the confidence that is required to support the purpose of the risk analysis and the decision to be made. To that end, the information and the uncertainty reflected in the risk estimates will also vary. Generally, more detailed risk analyses require more detailed engineering analyses and studies to try to better understand and reduce the uncertainty, when and where possible, and increase the confidence in the risk estimates.

In general, dam safety risk analyses can be divided into four broad categories or levels:

- Level 1 - Screening Level Risk Analyses
- Level 2 - Periodic Risk Analyses
- Level 3 - Semi-Quantitative Risk Analyses (SQRA)
- Level 4 - Quantitative Risk Analyses (QRA)

Each level provides a different set of tools and methods that are proportionate in terms of level of effort required, details considered, and confidence in their outcomes. These levels of risk analyses provide a suite of scalable approaches that provide information to promote critical thinking and guide a risk analyst's judgment. The risk analysis methods applied to each level are scalable and can be applied with varying degrees of effort (time, resources, and cost) to provide the appropriate level of accuracy, rigor, and confidence required to make credible risk informed decisions. It is important to understand that every decision does not necessarily require a high level of rigor, detail, and precision in the risk estimate in order to support a credible decision. These risk analysis levels vary in purpose and therefore in the data required, detail, and robustness of analysis, and in uncertainty and confidence in the results. However, in all cases the level of detail should only be what is needed to support the decision(s) that will be informed by the risk analysis. The analysis should be as simple as it can be, but not simpler. Figure 2-4 shows a general framework for each level of risk analysis.

These levels of risk analysis range from qualitative to quantitative approaches. In either approach a comprehensive identification, written description, discussion, and evaluation of factors that make events more or less likely to occur for each credible potential failure mode are documented. The magnitude of consequences related to a potential failure is also characterized, discussed, and documented.

Qualitative or semi-quantitative risk analyses can be desirable in some cases where it is desired to apply risk analysis principles to the decision making without the time, cost, and data/assessment requirements associated with a quantitative risk assessment; for

screening level analyses of an inventory of dams where it is desired to get a quick evaluation of the risks so that risk reduction studies and actions can be prioritized; and for sensitive cases that involve external interested parties that are more likely to understand and accept qualitative assessments rather than detailed numerical analyses (FEMA, 2015).

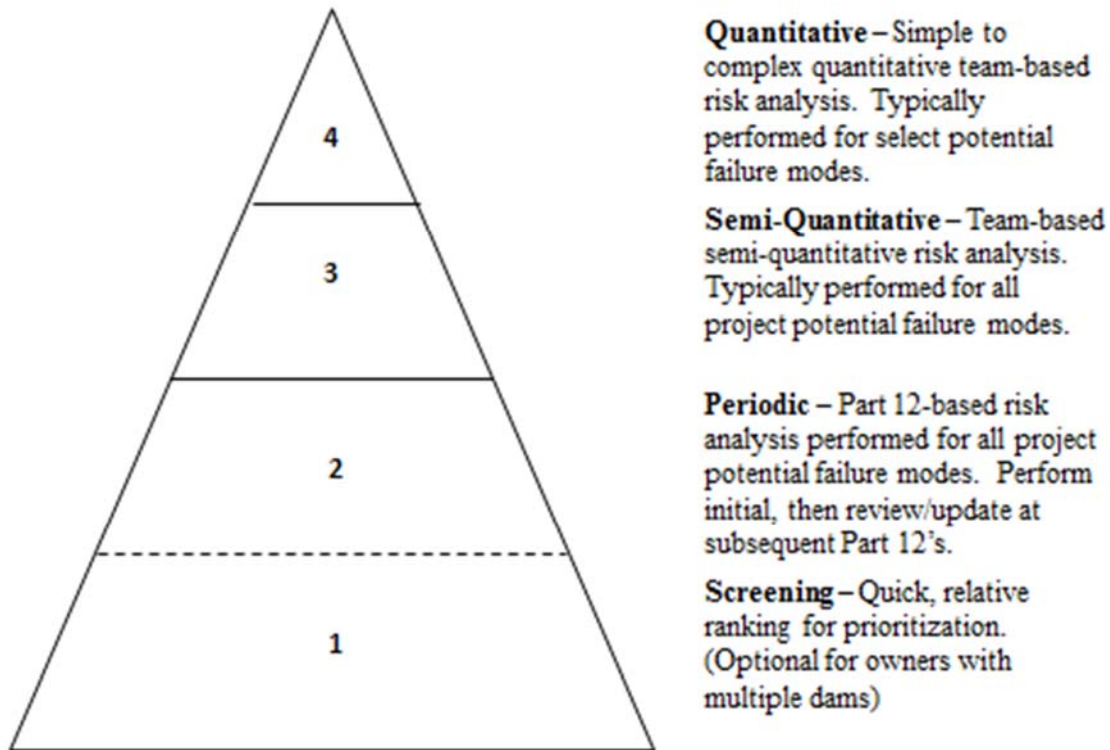


Figure 2-4. Level of Risk Framework

A brief overview of the characteristics of each level of risk analysis is shown in Table 2-1. Figure 2-5 illustrates the overall flow of the risk analysis process.

Additional information regarding each of the four levels of risk analysis is included in the following sections.

Table 2-1. Summary of Risk Analysis Levels

Level	Description	Purpose/Outcome	Type of Risk	Typical Level of Effort	Loadings	Consequences	System Response	Uncertainty
1	Screening	- Initial prioritization of inventory - Identify dams that are potentially very high risk that require immediate attention - Not appropriate for decisions	Incremental life safety Economic (in very general terms)	Minimal effort. Lead by a single individual or small team	Rapid assessment using simple, readily available tools	Simplified methods	Common potential failure modes (PFMs) using simplified tools	Qualitative to None
2	Periodic	- Identification of all PFMs - Prioritization of additional studies - Lowest level of risk analysis for decisions - Prioritization of inventory - Tolerable risk evaluation for existing conditions	Incremental life safety Economic Other	Low to moderate effort. Lead by a single individual (Independent Consultant) or a small team	Basic tools/ methods to estimate annual exceedance probability (AEP)	Simplified methods	Common PFMs using simplified approach	Qualitative
3	SQRA	- Project-wide assessment of risks - Identification of PFMs needing further study	Incremental life safety Economic Other	Effort can vary greatly depending on PFMs and issues. Team-based, facilitated.	Basic tools/ methods to estimate AEP	Simple to intermediate methods	Comprehensive evaluation of PFMs using semi-quant. approach	Qualitative
4A	QRA	- Lowest level of issue-specific risk analyses to determine if risks are tolerable or unacceptable	Individual life safety Incremental life safety Non-breach life safety Annual Prob. Failure Economic Other	Relatively simple/ routine models. Team-based, facilitated.	Simple loadings with no challenging technical issues	Relatively simple to estimate. Straight-forward.	Simple, common PFMs	Simple approach to quantify
4B	QRA	- Intermediate level of issue-specific risk analysis	Individual life safety Incremental life safety Non-breach life safety Annual Prob. Failure Economic Other	Moderate to high level of effort. Team-based, facilitated.	Intermediate difficulty. Use of additional experts may be required.	Intermediate difficulty. Use of additional experts may be required.	Intermediate difficulty	Moderate approach to quantify
4C	QRA	- Highest level of issue-specific risk analyses to determine if risks are tolerable or unacceptable	Individual life safety Incremental life safety Non-breach life safety Annual Prob. Failure Economic Other	Intense level of effort. Sophisticated/ detailed models. Team-based, facilitated.	Complex, difficult loadings. Use of additional experts likely to be required.	Challenging and difficult. Use of additional experts likely to be required.	Complex, multiple PFMs with multi-disciplinary teams	Detailed approach to quantify

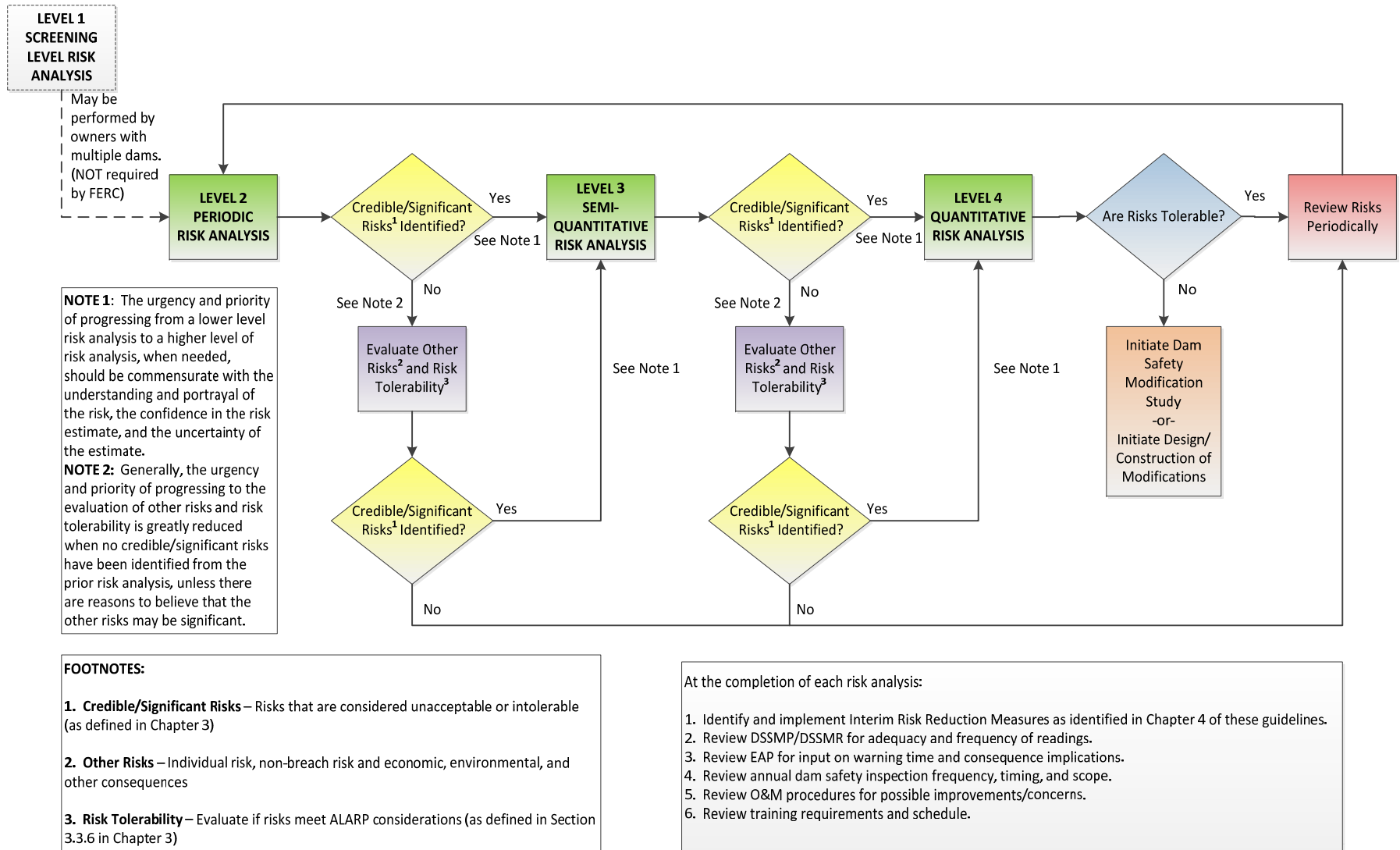


Figure 2-5. Relationship of the Levels of Risk Analysis within the Risk Analysis Process

2.3.2 Level 1 - Screening Level Risk Analyses

A screening level risk analysis is a relatively low effort, simplistic method to quickly assess risks (FEMA, 2015). The method uses simple tools and approaches in a systematic manner to evaluate each dam within an inventory. The goal is to develop relative risk estimates for each dam in a way that enables the relative risk among the dams to be evaluated and priorities for further study or remediation to be established.

In this process, each dam is screened expeditiously to identify the dams requiring urgent and compelling action with a low chance of missing any such dams. Also, a screening level risk analysis provides information for preliminary classification/prioritization of the dams in the inventory. Screening level risk analyses do not provide sufficient information to confirm that a dam requires no additional risk evaluation. Typically a screening level risk analysis is performed only once for every dam in an inventory.

Information on loadings, consequences, and analyses that relate to potential failure modes and serve as inputs to the analysis are very basic and limited, typically consisting of data already available or prepared just in advance of the screening effort. A screening level risk analysis can be a valuable tool for identifying uncertainties related to potential failure modes and significant dam safety issues. It can be used to prioritize additional actions and more in depth studies. Screening level risk analyses can either be made quantitatively or qualitatively (FEMA, 2015).

Typically, screening level risk analyses can be performed by an individual or a small team of individuals over the course of a less than a day to a few days effort.

Since the results of a screening level risk analysis do not provide absolute values of risk, the results of screening level risk analyses are not suitable for making a decision whether the risks of certain potential failure modes are tolerable or unacceptable.

The U.S. Army Corps of Engineers and Bureau of Reclamation developed and implemented screening-level risk tools early in their risk programs to provide an initial prioritization of their inventories of hundreds of dams; however, these tools are no longer being used or supported by these agencies as both have advanced to use higher-level risk analyses in their risk management processes.

In 2010 FERC developed a screening level risk analysis tool referred to as screening-level portfolio risk analysis (SLPRA). This risk tool uses a qualitative approach to estimate failure likelihoods and consequence categories of identified potential failure modes where the potential failure modes are subdivided into four categories – static, flood, seismic, and operational. The results for each dam (in the form of potential failure modes) are plotted in a risk matrix similar to Figure 2-6.

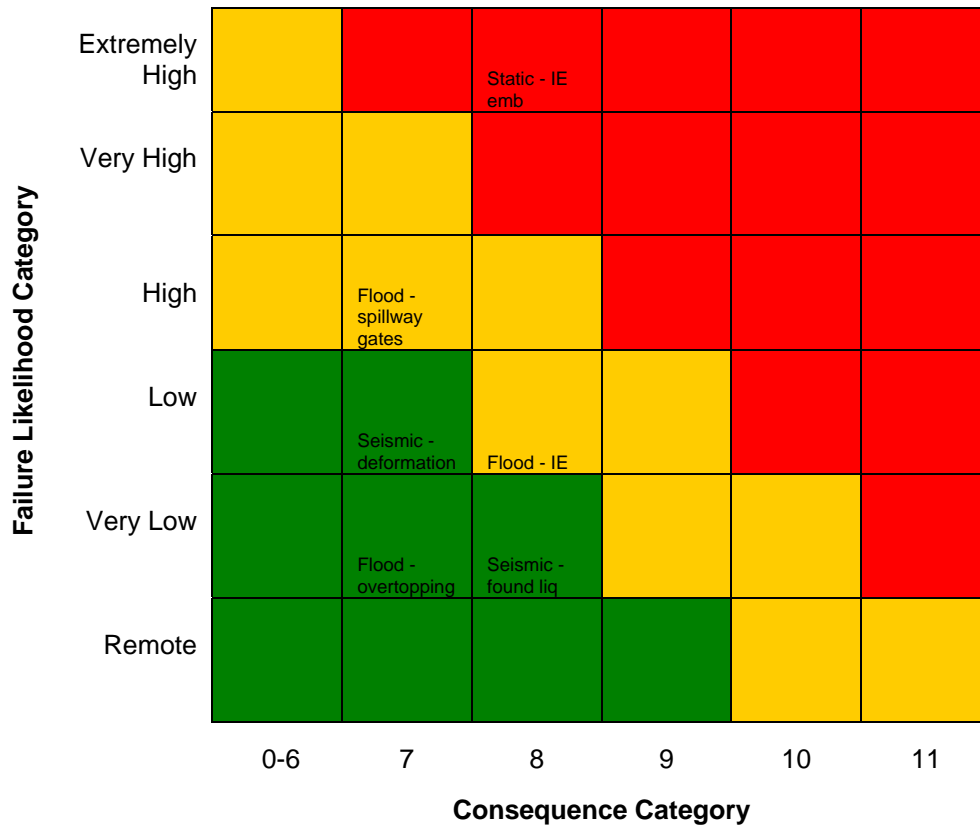


Figure 2-6. Example of SLPRA Risk Index

In order to provide a rough comparison of dams within an inventory, each block in the matrix can be assigned a numerical value, as shown in Figure 2-7. The highest rated potential failure mode from each of the static, flood, seismic, and operational categories can be assigned a score based on where they plot in the matrix, and summed to arrive at an inventory risk score. It should be noted that if the individual scores for all potential failure modes were used, the inventory risk score would become unduly influenced by the number of potential failure modes. It is important to understand that this score would add no value to the screening level risk analysis results for a given dam and would only be useful if used in the context of inventory-wide risk-based comparisons.

The inventory risk scores for each dam can be used to list the dams in order from high to low to provide a relative ranking. However, others factors may affect the priority ranking for the dams in a given inventory, depending on the needs. Therefore, the results from Level 1 risk analyses should be used very carefully and consistently, and with a full understanding of their intended use and limitations.

It should be noted that although FERC has developed a methodology to perform a Level 1 risk analysis, FERC does not require dam owners to perform this level of risk analysis.

Dam owners with multiple dams that may want to prioritize their dam safety activities may elect to use a screening level methodology such as SLPRA or some other screening level methodology as an aid to evaluate the relative risks of dams within their inventories.

Failure Likelihood Category	Extremely High	1000	3000	5000	10000	30000	50000
	Very High	500	1000	3000	5000	10000	30000
	High	300	500	1000	3000	5000	10000
	Low	100	300	500	1000	3000	5000
	Very Low	30	100	300	500	1000	3000
	Remote	10	30	100	300	500	1000
		0-6	7	8	9	10	11
		Consequence Category					

Figure 2-7. SLPRA Risk Index Scoring Matrix

2.3.3 Level 2 – Periodic Risk Analyses

Periodic risk analyses are more detailed and robust than Level 1 risk analyses. Periodic risk analyses have evolved from:

1. The need for a more detailed risk characterization than a screening level risk analysis, because the results of a screening level risk analysis are relatively crude. The results from a Level 1 risk analysis can provide a relative ranking and comparison of dams, but the results lack a level of detail and robustness that a more sophisticated and comprehensive risk analysis provides.
2. The opportunity and ability to leverage an already significant investment in time and effort to review documents and project information needed to perform a periodic inspection and evaluation of the project. The *Federal Guidelines for*

Dam Safety require that all dams undergo a periodic inspection and review that documents the condition of a dam at a point in time (FEMA, 1979). Significant effort is required to prepare for these periodic inspections and reviews. This effort includes reviewing project information, studies, analyses, performance and monitoring information, and other key project data. Through the course of these efforts, much project knowledge is amassed and evaluated. The incremental addition of a periodic risk analysis to this process enhances the value of the effort since additional engineering analyses and studies are typically not performed specifically for a periodic risk analysis because the analysis generally relies on existing information.

A number of Federal agencies have incorporated periodic risk analyses into their periodic inspection and review programs. Examples include:

1. The risk analysis methodology developed and used by BOR in support of their Comprehensive Review (CR) process.
2. The risk analysis methodology developed and used by the USACE in support of their Periodic Assessment (PA) process.

The primary purposes of a Level 2 risk analysis are:

- Evaluate the project potential failure modes and associated risks;
- Identify the need for additional studies and determine the priority for those studies;
- Identify and prioritize any data collection, analyses, and study needs;
- Identify operations and maintenance, monitoring, emergency action plan, training and other recurrent needs;
- Provide a better understanding of potential failure modes and a basis for future dam safety inspections and activities; and
- Provide support to inform dam safety decisions for taking action (or not) to better define risks through higher level studies, or reduce risks.

Level 2 risk analyses use semi-quantitative approaches, although quantitative risk analysis approaches can be used in some cases. The risk analysis for a periodic dam safety review can be performed by an individual or by small teams. A periodic risk analysis focuses on all potential failure modes in order to determine which ones are considered credible and significant at the dam.

Typically, the only life safety risk estimated from a Level 2 risk analysis is incremental risk. These risks are portrayed on a risk index or risk matrix chart, on an f-N or F-N plot, or by some other method. Individual risk and non-breach risk are typically not included in a Level 2 risk analysis. For those projects where economic consequences and other consequences (environmental, cultural, etc.) may be significant or large, as a minimum, a qualitative assessment of those consequences should be provided.

When possible, simple, qualitative assessments of as-low-as-reasonably-practicable (ALARP³) considerations should be included.

FERC is in the process of developing methodology to perform Level 2 (Periodic) risk analyses.

2.3.4 Level 3 – Semi-Quantitative Risk Analyses

A Level 3 risk analysis is typically the first step of risk analysis after a credible and significant PFM(s) has been identified from a Level 1 or Level 2 risk analyses or has been identified by some other dam safety activity (dam safety inspection concern, dam safety analysis result, performance monitoring concern, etc.). Level 3 risk analyses are performed prior to initiating a Level 4 risk analysis on a specific potential failure mode(s). Level 3 risk analyses typically employ a semi-quantitative risk analysis method.

The main purpose of a Level 3 risk analysis is to determine which potential failure modes require additional study and evaluation (Level 4 quantitative risk analysis) and which potential failure modes do not need additional study or risk analyses.

Level 3 risk analyses are typically the highest level and most robust risk analysis method that considers the full range of identified potential failure modes. Higher-order risk analysis methods (Level 4) typically only consider specific potential failure modes. Level 3 risk analyses are more robust than Level 2 risk analyses and are typically performed by a small team that is led by a trained risk facilitator. Generally, the results of these risk analyses are not of sufficient detail or confidence to make decisions about specific actions to take to implement permanent risk reduction measures; however, the results should have sufficient confidence to make decisions about specific actions or additional information needed to better define the risks.

In general, Level 3 risk analyses:

³ As-low-as-reasonably-practicable (ALARP) considerations are presented and discussed in Section 2.5.5.

- Take less time and effort to perform and are therefore less costly compared to jumping straight into a Level 4 risk analysis.
- Provide valuable information as to what studies would be needed to support a Level 4 risk analysis as well as the level of robustness those studies will likely need. This also serves to inform what sublevel of a Level 4 risk analysis is needed – A, B, or C, as discussed in Section 2.3.5.

Level 3 risk analyses can also be desirable in the following cases:

- A more detailed inventory screening assessment where it is desired to get a more detailed evaluation of the risks (than a Level 1 or Level 2 risk analysis) so that risk reduction studies and actions can be further prioritized.
- Non-dam structures, such as canal embankments or tunnels, etc. where it is desired to apply risk analysis principles to the decision making without the time, cost, and data/analysis requirements associated with a full blown quantitative risk analysis.
- Sensitive cases that involve the public to a high degree whereby those involved (including reviewers) are more likely to understand general descriptors than full blown numerical analyses.

The majority of the steps taken to perform a typical Level 3 risk analysis are very similar to that of a potential failure modes analysis (PFMA) workshop, and include:

- Review basic statistics and key features of the dam (e.g., type of dam, height of dam, reservoir volume, etc.).
- Review available design reports/design memos, construction photographs, and engineering studies/reports, site investigations, etc.
- Review historical operating condition loadings (reservoir levels and freeboard).
- Review performance monitoring information from visual observations and instrumentation.
- Review breach inundation studies (both “sunny day” and flood scenarios) including probable impacts to downstream dams, roads and bridges, recreation areas, permanent structures, recreation areas, and other property.

Additional information typically needed beyond that of a PFMA workshop include:

- Development of flood-frequency hazard curves and flood routings. Of particular note are the frequency of the flood of record, the frequency of the flood at the spillway capacity, the projected frequency of the probable maximum flood (PMF), and the flood frequency at the dam crest. Development of the flood frequency hazard curves are discussed in the *Best Practices for Dam and Levee Safety Risk Analysis* document (BOR/USACE, 2015).
- Development of probabilistic seismic hazard curves. Of particular note are the ground motions associated with the approximate return period of the maximum credible earthquake (MCE) and the ground motions used in any previously performed seismic analyses along with their approximate return period. Development of the probabilistic seismic hazard curves are discussed in the *Best Practices for Dam and Levee Safety Risk Analysis* document (BOR/USACE, 2015).
- Development of consequence estimates. Consequence estimates, generally loss of human life, for the most critical potential failure mode scenarios and locations are needed. Interpolation/extrapolation of this information can be used to develop similar estimates for other potential failure modes and for other potential failure mode locations. Development of consequence estimates are discussed in the *Best Practices for Dam and Levee Safety Risk Analysis* document (BOR/USACE, 2015).
- Other information that would help better define how the structure or feature would perform given the projected loads (flood, seismic, etc.).

The methodology for performing Level 3 risk analysis is included in the *Best Practices for Dam and Levee Safety Risk Analysis* (Semi-Quantitative Risk Analysis chapter) (BOR/USACE, 2015).

The following steps are taken for each identified potential failure mode:

- Develop/Update/Review the potential failure mode and its full description (See Chapter 14 of the *FERC Engineering Guidelines*). **It is important to develop the potential failure mode from initiation, through step-by-step development, to breach of the dam so that all participants have a common understanding of what is being estimated.** Sketches/figures depicting the PFM location and pathway can be very valuable. It is also important to understand what the breach (or uncontrolled release of the reservoir) entails, as this has a direct bearing on the consequences.

- Develop/Update/Review the factors making the potential failure mode more likely and less likely to occur, including analysis results and associated load probabilities where applicable, and identify the key factors.
- Ask each team member to make their individual estimate of the failure likelihood category prior to further discussion, considering whether the evidence is weighted more toward likely or unlikely, and then discuss.
- Elicit likelihood categories from each team member, along with the reasoning behind their estimate. This typically prompts discussion among team members. After the discussion has died down, the facilitator summarizes what has been said, proposing a “consensus” likelihood category and the reasoning why it makes sense, and then asking if there are any objections. If objections are raised, additional discussion ensues, and the process is repeated. If a consensus cannot be reached, the range of categories is captured along with the reasons for each.
- A designated recorder captures the information, including the likelihood category and the rationale for its assignment. The confidence in the rating is also captured, along with the rationale for its assignment and what additional information could be gathered to improve the confidence rating, if applicable.
- A similar elicitation process is repeated to arrive at a consequence category for each potential failure mode. It is especially important during this process to note differences between the likely breach flows associated with a potential failure mode, and what has been assumed in the breach inundation studies. In many cases, the breach outflow associated with a potential failure mode would be considerably less than assumed in some older inundation studies that were developed for the purpose of EAPs and not necessarily for estimating life loss consequences.

Typically the only life safety risk estimated from a Level 3 risk analysis is incremental risk. These risks are commonly portrayed on a risk index or risk matrix chart, by potential failure mode, an example of which is provided on Figure 2-8. Individual risk and non-breach risk are typically not included in a Level 3 risk analysis. A qualitative assessment of economic risk and other significant risks should also be included.

Simple, qualitative assessments of as-low-as-reasonably-practicable (ALARP) considerations should be included.

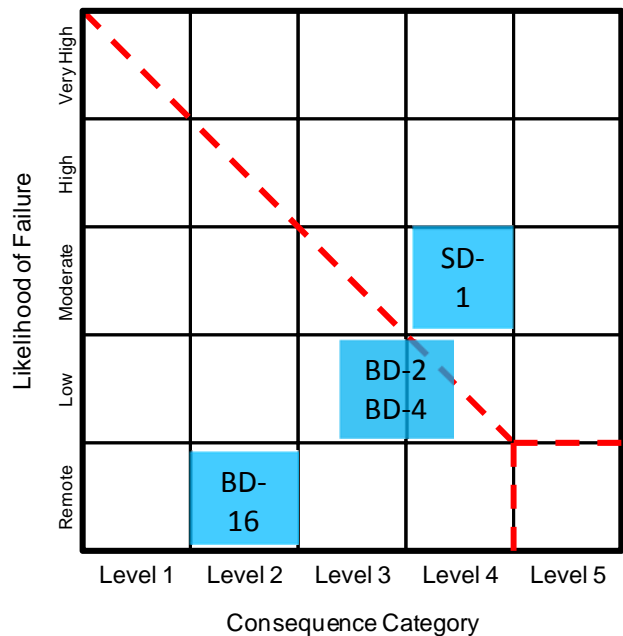


Figure 2-8. Example Portrayal of Level 3 Risk Analysis Results

Risk-Driver PFMs

- PFM BD-2: Backward Erosion Piping through the Main Embankment Foundation Material.
- PFM BD-4: Concentrated Leak Erosion (Scour) along the Main Embankment Outlet Conduit.
- PFM BD-16: Seismically Induced Cracks through the Main Embankment.
- PFM SD-1: Concentrated Leak Erosion (Scour) along the Saddle Dike Conduits.

2.3.5 Level 4 – Quantitative Risk Analyses

Level 4 risk analyses are typically focused on those potential failure modes that have been identified as credible and significant from the results of the Level 3 risk analysis. These potential failure modes may require additional engineering analyses, studies, or investigations to support a quantitative risk analysis. These supporting activities are completed to aid in quantifying and reducing uncertainty, if possible, and increasing confidence in the resulting risk estimates. Field explorations, material testing programs, detailed studies and analyses, or a combination of these may be performed to provide additional information for the risk analysis. Analyses and studies may focus on loadings, structural response, consequences, or a combination of these. The results of the Level 3 risk analyses should be used to help focus the scope of the Level 4 risk analysis studies.

Typically the scope of the Level 4 risk analysis is more rigorous than the level of detail executed in the Level 3 risk analysis and is intended to achieve a defensible, risk-informed basis for initiating permanent risk reduction studies or modifications or to decide that the risks are tolerable. Generally, estimates of the risk for potential failure modes that have some physical or visual manifestation can be established using existing data and performance history. Such may not be the case for potential failure modes that do not or have not had some visible or physical manifestation. In those instances the collection of additional data may be required if the missing data required to assess performance is not available or cannot be linked to a specific potential failure mode or observation.

Level 4 risk analyses are conducted primarily to inform the decision for making or not making dam safety investments. The risk analysis results should confirm that the dam safety risks are tolerable or not (with due consideration of uncertainty) and inform if risk reduction activities are warranted. Thus the scope of the Level 4 risk analyses is to estimate the risk (life safety, economic, and other risks) from all credible and significant potential failure modes and to estimate the non-breach risk of the dam. Secondary purposes of Level 4 risk analyses are:

- Verify/revise the prioritization of the project based on the findings;
- Verify if previously developed interim or permanent risk reduction measures are appropriate or need to be revised or if additional interim or permanent risk reduction measures are required; and
- Provide information to support prioritization and urgency of permanent risk reduction studies or modifications.

Level 4 risk analyses are scalable to fit:

- The purpose of the risk analysis;
- The complexity of the issues being studied - both in terms of technical difficulty/uniqueness of one or more engineering analysis methods and the potential failure modes or in the sheer number of challenging engineering issues or potential failure modes;
- The magnitude of the decision – including such things as high consequences, political or societal considerations, high financial investment being considered, and other factors;
- Uncertainty and confidence in the risk estimates;
- Ease or difficulty in estimating ALARP considerations; and
- Other factors.

Level 4 risk analyses can be simple and straight forward or can be highly complex and require sophisticated engineering analyses. To capture this range, Level 4 risk analyses are subdivided into three sublevels – Sublevel A, B, and C – with increasing robustness and effort from Sublevel 4A to Sublevel 4C. Typical characteristics of each sublevel are provided in Table 2-1.

In general, Sublevel 4A risk analyses are the most simplistic and basic quantitative risk analyses. Typically the loading, consequences, and system response probabilities are straightforward and do not include technical or analysis challenges; uncertainties are not large and are not expected to strongly influence the outcome; and ALARP considerations are relatively easy to determine. On the other extreme, Sublevel 4C risk analyses are

typically very complicated and have technical and/or policy challenges that must be addressed through state-of-the-art evaluations or analyses. Very often Sublevel 4C risk analyses have multiple challenging issues in a variety of different subjects. Because of the complexity of the issues, additional input is needed from highly experienced subject matter experts. This also translates into increased scrutiny and need for reviews by similarly experienced individuals. Probabilistic seismic and hydrologic loadings, where they strongly influence the risk analysis results, will typically require senior seismic hazard analysis committee (SSHAC)-type approaches as described in Bundtitz et al. (1997) and Kammerer and Ake (2012). In addition, consequence (loss of life and/or economic) and ALARP considerations can be complicated and require more detailed evaluations to inform the decision.

Sublevel 4B risk analyses are intermediate quantitative risk analyses and are typically the most common sublevel risk analysis. Sublevel 4B risk analyses typically include characteristics of both Sublevel 4A and 4C. Where certain aspects of the risk analysis (loadings, system response for certain potential failure modes, consequences, ALARP, etc.) strongly influence the results, additional analysis, robustness, and review may be needed for those issues and may resemble a Sublevel 4C risk analysis for those issues. Where aspects of the risk analysis are more straightforward and the final decision is not sensitive to the results, then those issues more closely resemble a Sublevel 4A risk analysis.

Through the course of performing a Level 4 risk analysis, the risk analysis might start out at Sublevel 4A and as the results of preliminary evaluations and analyses become available, the risk analysis may elevate to Sublevel 4B or 4C. The reverse is also possible.

Regardless of the sublevel of Level 4 risk analysis, the general steps of a Level 4 risk analysis include (adapted from USACE, 2014):

- Review/Revise/Update the potential failure mode analysis performed at the Level 3 risk analysis;
- Confirm/Identify which potential failure modes will be carried forward into the analysis;
- Develop event trees and fault trees (as applicable) for each potential failure mode;
- Develop loading functions (hazard curves) for loading events to be carried forward in the risk analysis;
- Determine the conditional probability of failure for each potential failure mode carried forward in the risk analysis;

- Estimate dam breach or other releases that may occur and the inundation downstream;
- Estimate the consequences associated with each potential failure mode carried forward in the risk analysis;
- Calculate risk estimates for incremental risk, ‘non-breach’ risk, and other risks;
- Build the case for why the risk estimates make sense and are consistent with the current conditions of the project;
- Compare the incremental risk to the FERC-D2SI tolerable risk guidelines for life safety (see Chapter 3); and
- Develop risk reduction alternatives, as appropriate, and evaluate whether risks are considered ALARP for the alternatives. Build the case for why the recommended actions are consistent with the risk estimates and conditions of the project.

The FERC-D2SI will provide guidance on the selection of the most appropriate risk estimating process and methodologies to be employed in a Level 4 risk analysis. USACE and Reclamation have developed risk analysis methodology guidance. Except as otherwise noted by FERC-D2SI, risk analyses should use the latest version of the *Best Practices in Dam and Levee Safety Risk Analysis* as a guide to the risk analysis process (BOR/USACE, 2015).

Typically the entire suite of risks is estimated for a Level 4 risk analysis. These include incremental life safety risk, non-breach risk, individual risk, economic risk, and other significant risks.

Level 4 risk analyses are also performed in support of permanent risk reduction modification studies. The risk analysis supporting these studies leads to definitive decisions and documentation to support dam safety actions to achieve reduction in life-safety risk, economic risk, and environmental risks. Additional data is typically gathered, as appropriate, to support the decision to be made. The primary purposes of the Level 4 risk analysis for these studies are the determination or update of the risk estimate for the incremental and non-breach risk; identification, evaluation, documentation support for, and recommendation of, long-term risk management measures; and the estimation of the incremental risk, the ‘non-breach’ risk, and residual risk of the remediated project.

The risk analysis developed in support of risk reduction studies must be reviewed and updated at the 90-percent final design and again after implementation of the risk

reduction measures (i.e., after construction) to determine if the risk management objectives were achieved. Generally this is not a large effort unless details emerge from the design or construction that impact the risk estimates. The scope of this work will vary depending on the potential failure mode being addressed, the design and construction details, and how well the risk reduction alternative was originally defined.

2.4 RISK TEAM

The composition of risk teams for risk analyses depends on the level of the risk analysis, the complexity and diversity of the potential failure modes being evaluated, and other factors. In a very general sense,

- Level 1 risk analyses are typically performed by an individual that may or may not have input or assistance from other subject-specific experts.
- Level 2 risk analyses are typically led by an individual with input provided from one or more subject-specific individuals.
- Level 3 risk analyses are typically performed by a small team of individuals that cover a broad range of expertise and led by an experienced risk facilitator.
- Level 4 risk analyses are typically performed by a multi-disciplinary team of individuals that cover a broad range of expertise and led by an experienced risk facilitator.

2.4.1 Composition

Risk teams typically vary in composition depending on the purpose, scope, level of risk analysis, complexity, technical issues, and other factors being evaluated in the risk analysis. In general, all risk teams for Level 3 and Level 4 risk analyses include:

1. One or more facilitators (or co-facilitators)
2. Subject matter experts
3. One or more note-takers

Other key individuals participating on the risk team include:

1. Project manager – An overall project manager should be assigned to establish, monitor, track, and revise the project scope, schedule, and budget, as appropriate, and to coordinate the many individuals and entities that may be involved in the risk analysis.
2. Support personnel – Those individuals responsible for performing engineering analyses and evaluations and gathering information in support of the risk analyses.
3. Owner personnel – These include engineering managers, dam safety personnel, operations and maintenance personnel, and other dam owner personnel who have knowledge of the project.

4. FERC staff – Dam safety engineers from headquarters and regional offices.
5. Review personnel – Internal or external reviewers, depending on project requirements.
6. Software operator – For Level 4 risk analyses, one or more software operators are required.
7. Other personnel – These may include personnel from emergency management agencies, current and former Part 12D independent consultants, engineering consultants with prior experience with the project, other regulators, and others.

Some of the personnel listed above may serve as the facilitator, subject-matter experts, or note-taker, provided they meet the qualifications described in Section 2.4.3.

In addition, other interested parties and observers may be in attendance during all or parts of a risk analysis meeting.

2.4.2 Roles and Responsibilities

The composition of a risk analysis team is similar to that of the PFMA core team described in Chapter 14 of the *FERC Engineering Guidelines*, with the exception of the addition of a software operator to the risk analysis team. However, the roles and responsibilities of these team members are typically much more defined in a risk analysis, as described in the sections below.

2.4.2.1 Facilitators

Facilitation is a critical part of the process to develop credible risk estimates during the risk analysis meeting (BOR/USACE, 2015). In general, the facilitator:

- Meets with the team prior to a risk analysis to ensure engineering analyses are completed to support the team risk analysis and ensure the team composition is appropriate to develop credible risk estimates.
- Facilitates the team risk analysis, helping the team develop potential failure modes, event trees, strategies for estimating risks, and developing ranges of likelihood and consequence estimates.
- Reviews the final report ensuring that:
 1. there is enough description that someone picking up the report in the future can understand what the team was thinking and why;

2. the team's estimates, factors, and justifications have been captured in the report;
3. all work has been performed correctly and in accordance with sound risk analysis principles; and
4. the results are adequately portrayed, and the case has been made as to why they make sense. (The facilitator is not typically the author of the report, but can be.)

Facilitators shoulder a heavy load as they are primarily tasked to ensure (BOR/USACE, 2015):

- Risk analysis methodologies are followed to develop risk estimates
- The methods used during the analysis are consistent with current practice
- Alternative viewpoints are elicited, discussed, and recorded
- The team contains the appropriate staff to arrive at a credible risk estimate
- The final report contains potential failure modes that are adequately described with sufficient documentation to support the team's risk estimates
- The case built reflects the information developed during the risk assessment
- The case built follows the general principles described in Section 2.6.3

The facilitator leads the risk analysis meeting to ensure the meeting stays on track and that the team focuses on the issues to be addressed. The facilitator may have kick-off discussions on the objectives of the risk analysis (owner's needs, regulatory requirements, etc.); team makeup; constraints of time, manpower, lack of knowledge; bias; or work already accomplished (including previous risk analyses).

The facilitator monitors the flow of the meeting and initiates adjustments during the meeting to help maintain focus. The facilitator may use the verbal descriptors provided in the section on Subjective Probability and Expert Elicitation in the *Best Practices in Dam and Levee Safety Risk Analysis* document (BOR/USACE, 2015) during the meeting to help the team in formulating their probability estimates.

The facilitator is responsible for ensuring the risk estimates are solicited and provided by only those members of the risk team that have the requisite qualifications to provide the risk estimate for each node or estimate being provided. Individuals providing risk estimates should meet the qualifications of a subject matter expert for the appropriate level of risk analysis as discussed in Section 2.4.3.2. **The facilitator does NOT provide risk estimates during the course of the risk analysis meeting**, but should point out inconsistencies or other information that the facilitator feels the team has not adequately considered.

Flip charts are useful in that they provide a permanent record of the team discussions, and allow the facilitator to capture important points of the discussion without having to direct a note taker (BOR/USACE, 2015). The facilitator also works with the note taker and software operator throughout the meeting to ensure the proper information is being collected for future documentation.

It has proven to be advantageous to have two facilitators present for the risk analysis meeting. This permits both facilitators to remain focused throughout the process by switching off and supporting the facilitation process. It also provides senior level knowledge to help facilitate difficult areas of the risk analysis that are specific to a given engineering practice, and provides an opportunity for less experienced facilitators to learn from more senior facilitators. This practice of using two facilitators, and the associated cost, has proven to be extremely valuable. For some risk analyses, the co-facilitators may not be needed.

2.4.2.2 Subject Matter Experts

Subject matter experts (SME's) are those select members of the risk analysis team that provide qualitative or quantitative risk estimates based on their knowledge, experience, and judgment within their area(s) of expertise/technical discipline. Other members of the risk team may provide comments, discussion, and even presentation of information, results of engineering analyses/evaluations, or summary of some other type of information; however, typically only subject matter experts provide risk estimates.

Other tasks and roles that SME's fulfill:

- Review project data and engineering analyses
- Critically challenge analysis assumptions and findings and determine adequacy of analyses/information available
- Understand limitations of data/applicability of analyses/etc.
- Provide expert judgment when additional analyses are needed

SME's only provide risk estimates for those issues that they have the requisite knowledge and expertise. SME's must know the limits of their technical expertise.

2.4.2.3 Note Taker

The note taker is perhaps the second most important person in a risk analysis (other than the facilitator). It is the responsibility of the note taker to capture, in writing, the key discussions and concepts during the risk analysis. A good note taker can capture a group discussion in a few sentences and does not attempt to simply record each statement made. Comprehensive notes are of utmost importance as they form much of the content of the

risk analysis report and record the key inputs, assumptions, and thoughts of the subject matter experts in building the case for the results of the risk analysis.

The note taker should make sure all notes are clear and capture the discussions of the group, including the intermediate decisions that are made prior to moving on to the next subject. It can be helpful if the note taker uses a computer projector to display the notes in real-time during the risk analysis meeting. This helps so that the participants can see what is being captured and to make sure the notes adequately capture the information, intent, and decisions. (A word of caution - the risk team members cannot get caught up in wordsmithing each and every word of the notes. Otherwise, the risk meeting will get bogged down and progress will come to a halt. Wordsmithing should be reserved for reviewing the final report.)

Other tips:

- Taking notes during a risk analysis meeting is distinctly different than administrative note taking. It is extremely helpful if the note taker is an engineer with knowledge of the project in general. This is important because the note taker must be familiar with engineering terms and concepts so that they can be appropriately and timely captured during the discussions.
- It can be more efficient if the note taker is the primary author of the risk analysis report. This provides an added motivation of the note taker to record good notes and can improve the quality of the final product.
- It is also important to identify a backup or secondary note taker to supplement or provide a backup set of notes in case the primary note taker becomes distracted or cannot be present.

2.4.2.4 Software Operator

A software operator is required for Level 4 risk analyses. The software operator is responsible for inputting risk analysis estimates into the computational risk software. The software operator should be trained in the software being used and should have a clear understanding of probability theory associated with risk analyses. When possible, risk estimates should be input into the software as close to real time as possible so that results can be vetted and missing or incorrect information can be corrected or adjusted. Many times it will not be possible to input the risk estimates in real time because of the complexity of the event tree construction and other factors. Generally the risk analysis should not be delayed in waiting for the software operator to complete their tasks. Instead, the risk analysis should proceed so long as adequate notes have been captured by the note taker.

2.4.2.5 Others

Other personnel in attendance at the risk analysis meeting may include supporting personnel (operations/maintenance personnel, engineering support staff, emergency management personnel, and management staff) and interested parties/observers. These individuals typically participate in the discussions during the risk analysis meeting, but generally do not provide risk estimates unless they have the qualifications of a subject matter expert.

Owner's staff – The owner's staff/personnel may serve various roles on the risk team provided they meet the qualifications. The owner's personnel may serve as SME's for various aspects and topics of the risk analysis. For example, operations personnel may serve as SME's for operational aspects of the risk analyses. Engineering staff and managers may serve as SME's for those issues they possess the technical abilities and experience, provided they meet the qualifications of an SME.

FERC staff – FERC personnel may serve as an SME for those issues they possess the technical abilities and experience and meet the qualifications of an SME. It should be noted that the presence of FERC personnel at the risk analysis meeting does not constitute an endorsement or agreement of the FERC with the final results of the risk analysis.

Independent Consultant – The independent consultant may serve as an SME for those issues they possess the technical abilities and experience and meet the qualifications of an SME. An independent consultant cannot serve as a risk analysis facilitator for those projects in which they also served as the independent consultant within the last ten years.

Some additional guidance:

1. Diversity in the members of the risk team is an important factor in a successful risk analysis. Participation from only the owner or only from members of a single company or organization can lead to a strong bias in the results and outcome and may invalidate the risk analysis results. This may not be avoidable, but should be recognized.
2. Not everyone present at the risk analysis meeting provides a risk estimate. It is the responsibility of the facilitator, working with the individuals in the room, to determine who provides estimates for each node of each potential failure mode. Inclusivity is not an objective of a risk analysis. Individuals must have the requisite knowledge, experience, and qualifications to provide risk estimates.

2.4.3 Qualifications

The following sections present a brief summary and general guidance regarding the background, experience, training, and other qualifications of key risk analysis team personnel.

It is recognized by the FERC that the qualifications presented in this section are lofty and may be difficult to attain in the initial stages of risk analysis in support of RIDM. In special circumstances, FERC may elect to reduce the minimum qualifications of certain key risk personnel described in this section when, in the opinion of the FERC, the qualifications of those individuals will not adversely impact the execution or results of the risk analysis study.

2.4.3.1 Facilitators

The minimum qualifications of a risk analysis facilitator depend on the level of risk analysis and guidelines are listed in Table 2-2.

A co-facilitator or secondary facilitator does not have to meet the qualifications of a facilitator provided that the lead facilitator is present and monitoring the work of the co-facilitator and intervening, if needed.

2.4.3.2 Subject Matter Experts

The determination of the minimum qualifications/experience of a SME is difficult and, like those for a facilitator, depends on the level of the risk analysis. Table 2-2 provides guidelines for minimum qualifications for a SME. It is recognized that not all SME's are equal.

Ideally each risk team will have between four to six qualified SME's as risk estimators for each risk estimate. Not all SME's will be qualified to provide risk estimates for each and every node or risk estimate. The facilitator will make the determination as to which SME's will serve as risk estimators for each node or risk estimate beforehand. Too many risk estimators can lengthen the time and effort of the risk analysis while too few risk estimators will not result in enough input from individuals with different experience or understanding to have a valid estimate.

Experience has shown that it will likely be difficult to find four to six SME's for risk estimates that are related to loading (seismic and hydrologic) as well as consequences. In these cases it may be acceptable to reduce the number of SME's to two to three for these particular estimates, as well as for other relatively straight forward estimates as determined by the facilitator.

2.4.3.3 Note Taker

The minimum qualifications of the note taker are listed in Table 2-2. Note takers should be an engineer with at least five years of dam safety experience.

The note taker should have verbal and written command of the English language and can type or write quickly enough to capture and document key information and discussions. The note taker should have the ability to understand engineering terminology and technical discussions and to discern what points and discussions are important to capture.

2.4.3.4 Software Operator

The minimum qualifications of the software operator are listed in Table 2-2. Software operators should be an engineer with at least five years of dam safety experience. Software operators should have training and experience in using the risk analysis software being used for the risk analysis. It is also important that the software operator have excellent spreadsheet and software skills and like the note taker, the software operator should have the ability to understand engineering terminology and technical discussions and to discern what points and discussions are important to capture.

Table 2-2. Guidelines for Minimum Qualifications of Key Risk Analysis Personnel

	Facilitator					Subject Matter Expert	Software Operator	Note Taker/Recorder
	Level 2 Periodic	Level 3 SQRA	Level 4A QRA	Level 4B QRA	Level 4C QRA			
Dam Safety Experience								
Years of dam safety experience (investigations, studies, designs, construction, etc.)	10	10	15	20	20	10	5	5
Primary author on dam analysis, design, or construction (number of technical papers or significant reports authored)		5	5	7	10	5		
Lead reviewer or member on expert panel/board for dam studies, design, or construction (number of projects)					4			
Lead technical role for one or more technical disciplines for dam analyses (number of projects)		2	2	4	4	5		
Author, presenter, or participant in dam failure or incident case history (number of case histories)		2	3	4	5	1		
Risk Analysis Experience (number of projects)								
Participant as a subject matter expert (SME) for a risk analysis		2	2	4	6			
Primary author of Level 3 risk analysis reports			2					
Primary author of Level 4 risk analysis reports				2	2			
3 rd party reviewer/independent review of Level 3 risk analysis reports			2					
3 rd party reviewer/independent review of Level 4 risk analysis reports				2	5			
Facilitated level 3 risk analyses			2					
Facilitated level 4A risk analyses				2				
Facilitated level 4B risk analyses					2			
Primary author of a technical publication on dam safety risk analysis					2			

Training*								
Base Courses								
Overview of Risk Analyses	R	R	R	R	R	R	R	R
Best Practices in Dam Safety Risk Analyses		R	R	R	R	R	S	S
Level 2 Risk Analyses	R							
Level 3 Risk Analyses		R	R	R	R	R		
Facilitation			R	R	R	S		
Loadings and Consequences								
Hydrologic Loading		S	S	S	R	R		
Seismic Loading		S	S	S	S	R		
Consequences		S	S	S	R	R		
Failure Modes and Risks								
Internal Erosion Mechanics					S	R		
Internal Erosion Risks					S	R		
Overtopping/Overwash/Erosion of Soil and Rock					S	R		
Seismic Analysis of Concrete Structures and Gates					S	R		
Seismic Analysis of Embankments					S	R		
Operational Risks			S	S	R	R		
Risk Analysis								
Failure Modes and Event Tree Construction			S	R	R		R	
Risk Analysis Software Tools			S	R	R		R	
Portrayal of Risks to Support Decisions			S	R	R			
Other								
Professional License Requirements	PE	PE	PE	PE	PE	PE	PE/PG	
Regularly participates in professional society meetings/conferences/workshops/publications (USSD, ASDSO, or similar)		Yes	Yes, typically a member	Yes, typically a technical committee member	Yes, typically a technical committee member	Yes, typically a technical committee member	Yes, typically a member	

R – Strongly Recommended

S – Suggested

*Training courses listed in this table are currently being developed by FERC. A training course schedule will be published and updated by FERC.

2.5 EXECUTION

2.5.1 Preparing for a Risk Analysis

Good planning, preparation, and communication are essential elements to a successful risk analysis. Ignoring or not fully integrating any one of these factors into the risk analysis process will likely result in an inadequate risk analysis that could jeopardize the results of the analysis and nullify the decision.

2.5.1.1 Plan

A detailed risk analysis project plan must be developed prior to initiating Level 3 and Level 4 risk analysis work. At a minimum, the risk analysis project plan must include:

1. The objective(s)/purpose of the risk analysis.
2. Project description.
3. Summary of prior work, including a list and category for each potential failure mode from the most recent Part 12D inspection report.
4. The scope of work for the level (and sublevel as appropriate) of risk analysis, including any additional engineering analyses needed to support the risk analysis.
5. The proposed project team, including qualifications of individuals, roles and responsibilities, communication protocols, etc.
6. Any special considerations, such as proposed deviations from risk methodologies described in Section 2.5.4 or special considerations in the evaluation of ALARP described in Section 2.5.5.
7. The project schedule, including key milestones, meetings, and product delivery dates.
8. List of deliverables.

The scope of work must contain a detailed description of data preparation and site characterization efforts and must identify any hydrologic, seismic, consequence analyses, or instrumentation evaluations, etc. needed to adequately understand, evaluate, portray, and communicate the risk at the project and project purpose accomplishments. In some cases additional site geologic information or testing may be required.

Five copies of the risk analysis project plan must be submitted to the FERC Regional Engineer for review and acceptance. The risk analysis project plan should be submitted to the FERC a minimum of six months prior to initiating any investigation, analyses, or other efforts in preparation of the risk analysis work. FERC will review the plan and provide comments to the dam owner within 60 days of receiving the plan.

It is highly advised that a scoping meeting(s) be conducted with FERC staff prior to developing the risk analysis project plan. FERC staff can provide guidance on

expectations, potential pitfalls, and discuss potential scope and needs for engineering analyses in support of the risk analysis. It is recommended that the scoping meeting(s) take place prior to submitting the risk analysis project plan and a follow up meeting(s) take place a minimum of three months prior to any facilitated risk analysis meetings to make sure all the preparation tasks are on schedule and the required information will be available in sufficient time for the facilitated risk analysis meeting. These coordination meetings may be face-to-face or web-based/conference calls.

2.5.1.2 Preparation

All information relevant to the level of risk analysis to be conducted should be compiled prior to the risk analysis. Preparing for a risk analysis takes substantial effort. Lack of preparation is also the leading cause of schedule delays in conducting a facilitated risk analysis meeting/elicitation and needing to conduct subsequent risk analysis meetings which lead to project schedule and budget growth. Preparation activities for Level 3 and 4 risk analyses include:

1. Compile all available project information/files.
2. Identify additional information/analyses/etc. needed to perform the risk analysis. These include analyses to support:
 - a. Loadings
 - b. Engineering evaluations and analyses to support system response estimates
 - c. Consequences
3. Meeting preparation and logistics.

Compile Background Information – All background information on the project must be identified, gathered, collected, and assimilated for review by the risk team. This information should be provided to the risk team prior to the facilitated risk analysis meeting and would also need to be available during the risk analysis meeting. The general rule is: collect all information on the project. If there is a question about the need to bring/collect certain material, the facilitator and owner should discuss this in advance.

The types of material that should be collected and reviewed (if available) are identical to that required for a PFMA session (See Chapter 14, *FERC Engineering Guidelines*) and include but are not limited to:

- Original and subsequent design investigations and planning study reports and exploration data (boring logs, laboratory testing reports, etc.).
- Original and subsequent design memos, analyses, design drawings and original construction reports/photographs/inspection reports/as-built drawings/etc.

- Any FERC or state agency construction inspection reports (these have been found to be extremely useful, particularly if the original construction predates the Federal Power Act).
- The most recent surveys for each of the project structures (i.e. horizontal and vertical survey data). A detailed survey of the crest of all structures including principal and emergency spillway crest elevations to confirm the freeboard assumed in the discussions. Elevations of natural grounds that could result in overflows around the structures should be considered. Also, the datum of the project relative to surrounding grounds should be stated (i.e., conversion of project records to NGVD).
- Recent and historic meteorological and pertinent river records from project or nearby dam or gage records (<http://waterdata.usgs.gov/nwis>).
- Current hydrologic studies and the associated flood routings and any hazard / consequence analyses.
- Operation records(particularly historic) of primary and secondary (e.g. fuse plugs) spillway discharge rating curves, mechanism and response times for opening (i.e., stanchion gates, bulkheads, flashboards, gates) and problems (i.e., ice, debris).
- The most recent seismic loading parameters that have been prepared for the site and print records of recent seismic activity (<http://neic.usgs.gov/>).
- The current Emergency Action Plan.
- The most up-to-date aerial photographs of the downstream areas that could potentially be impacted by failure of the project structures.
- Current or most recent dam safety engineering analyses, including stability and stress analyses.
- The most recent monitoring and instrumentation data along with the historic records of monitoring data (Dam Safety Surveillance and Monitoring Plan and Reports). Large scale, easily readable, plots of monitoring data over the life of the dam have proven extremely valuable and should be available at the PFMA session. The licensee or consultant should also provide verification that the instrumentation is properly functioning.
- The most recent underwater inspection report(s).
- Any incident reports.

The owner should establish a means to retain/archive all the information collected for the risk analysis meeting. Appropriate information discovered, collected, or generated from the risk analysis work should be included in an update of the Supporting Technical Information Document (STID).

Assessment of Additional Work/Analyses - Once all the available information and background data has been compiled and reviewed, the risk team must assess what additional information, analysis, or work is needed, if any, for the risk analysis. The level of detail and scope of the information and analyses needed for the risk analysis will be

based on the level and complexity of the risk analysis. Sensitivity, uncertainty, and confidence needs will also influence this.

Loading information/analyses

Examples of information/analyses that might be needed to provide input to additional engineering analyses and the risk analysis include:

- Daily reservoir and tailwater data to develop reservoir elevation stage-frequency curves.
- Stream gage data to support development of hydrologic loading frequency curves.
- Need for more detailed hydrologic studies (paleoflood, site-specific precipitation, stochastic modeling, etc.) to support hydrologic loading frequency curves.
- Need for more detailed seismic studies to support the development of probabilistic seismic hazard curves and other seismic hazard inputs time history curves, spectral acceleration, etc.).

Based on the results of the loading analyses, the team will have to determine if the results of the existing engineering analyses can be used or if supplemental engineering analyses are needed due to changes in seismic or hydrologic loading.

System response information/analysis

Additional information and analyses may be needed in support of system response estimates. Examples may include:

- Developing geotechnical/geological cross sections at key locations to be able to assess the continuity of various units/deposits.
- Plotting piezometric water surface(s) on geologic cross sections to be able to understand the movement of groundwater and estimate hydraulic gradients through subsurface materials.
- Preparing detailed drawings that synthesize all pertinent data including boring logs, instrumentation, geologic features, laboratory data, etc.
- Plotting gradation tests of various embankment or foundation materials.
- Plotting laboratory test results to estimate the mean and range of material property values.
- Performing filter compatibility analysis of various subsurface materials.
- Performing engineering evaluations (stability, seepage, deformation, stress, erodibility, etc.), including sensitivity analysis and probabilistic analysis, where appropriate.

Additional information and guidance is provided in the *Best Practices for Dam and Levee Risk Analysis* (BOR/USACE, 2015).

Consequence information/analysis

Consequence estimates should be based on reservoir levels corresponding to potential failure modes, dam break studies, and associated flood routing/inundation studies. The team should evaluate if the current inundation mapping scenarios are appropriate and can be used for consequence estimates or if additional supplemental analyses are required. Additional dam breach and inundation mapping may be required if the current analyses do not adequately model the breach characteristics (location, timing, width, etc.) of the potential failure mode(s) being modeled and reasonable extrapolations or interpolations cannot be made with confidence. Additional information in support of the risk analyses may include:

- Population estimates within the inundation area
- Dam failure flood flow characteristics such as depth, velocity, and travel time
- Estimates of warning times and mobilization rates/effectiveness
- Evacuation routes
- Economic estimates
- Other factors

Meeting Preparation and Logistics – Some advice related to meeting logistics:

- Meetings should be scheduled far in advance. Risk facilitators and many subject matter experts have full work schedules and coordinating such ‘in-demand’ individuals can be difficult. Rescheduling meetings can add significant delays to the project schedule.
- Background information and reports should be readily available on-site at the risk analysis meeting. Not all information has to be in hard copy form. Key pieces of information should be captured for inclusion in the report.
- Flip charts and white boards should be available so figures and sketches can be displayed to the participants. Large size non-distorted scale drawings posted on the walls allows for sketching potential failure modes with proper appreciation for differential heads, gradients, etc. Cameras should be available to capture these images.
- A projector(s) should be used to capture and review written notes being taken during the risk analysis and to display drawings, photographs, and other data that may be available.

- The meeting room size and environmental considerations (noise, temperature, lighting, etc.) should be appropriate for the number of participants expected to attend the meeting. It may be more challenging to find appropriate meeting rooms/locations for larger size groups.

2.5.1.3 Communication

Communication is a critical element to the success of a risk analysis. Depending on the level of risk analysis and complexity of the technical issues, risk analysis teams can be small in size or can be large and include participants from numerous agencies, organizations, and departments. In every case, communication of information to all parties is critical. Some good communication practices for risk analyses include:

- Schedule an initial kickoff meeting with all parties. Communicate the overall plan to conduct the risk analysis, including scope of work and schedule. Identify critical milestones and information needed by whom and by when.
- Communicate changes to the scope of work and schedule changes with all parties in a timely fashion.
- Record written meeting minutes and provide copies of the minutes to all parties. Highlight/summarize key decisions, issues, and actions in the minutes, identifying responsible parties and schedule commitments.
- Identify and resolve issues in a timely fashion.

2.5.2 Risk Analysis Meeting

If the risk team has been chosen properly, people will enter the risk analysis meeting with the appropriate expertise, an open mind, and a willingness to achieve the best possible results (BOR/USACE, 2015). When this occurs, appropriate interactions take place, and additional ideas expand from those being discussed. This type of approach reaches a better conclusion than any of the individual members could have on their own. However, sometimes the team may stumble along one or more of the following lines. The risk analysis facilitator must recognize when this is occurring, and try to direct the group toward a more positive direction (BOR/USACE, 2015).

- A dominant individual may drive the way the team goes by “bullying” everyone into thinking the way they do. It takes a fairly strong facilitator to deal with this, and usually requires emphasizing and bringing out the opposing point of view as well as drawing others into the conversation.

- People may not say what they really feel for fear of appearing unknowledgeable, and will tend to go along with the rest of the group even though they have important input. This requires the facilitator to draw out their opinions by directing questions specifically at these individuals.
- A contrary individual may have valuable information even though their approach to communication may be difficult or challenging to the rest of the group. This information and these opinions should not be quickly dismissed without due consideration.
- The group gets tired due to the rigors of the meeting, and people agree just to get it done. The facilitator is not immune to this trap. If it is obvious that proper attention is not being paid to something, it is important to stop, take a break, and discuss ways to invest proper time for the evaluation.

2.5.2.1 Meeting Preparation

Preparation for a risk analysis meeting is discussed in the Section 2.5.1 above. Strong consideration should be given to delaying the risk analysis elicitation meeting if:

- Important information is missing or unavailable.
- The results of any engineering analyses performed to support the risk analysis are not yet available.
- Key personnel (facilitator, key subject matter experts, etc.) are not able to attend the meeting.

Conducting the meeting without this information or key personnel has the potential to jeopardize the results of the risk analysis and may cause the need for a follow on meeting to be scheduled.

2.5.2.2 Meeting Agenda

An example risk analysis meeting agenda is included in Appendix 2A. The agenda for each risk analysis meeting will vary depending on the project-specific issues.

2.5.2.3 Conducting the Risk Analysis

A critical first step in a risk analysis is an evaluation of the design, construction, analysis, and performance of a dam and an identification of the specific potential failure modes that apply to that dam. If critical potential failure modes are overlooked, the risk analysis results will be incomplete and misleading.

It should be recognized that each dam is unique in terms of purpose, geologic setting, design, structure, operations, and consequences. While certain dams may be similar to other dams in type, design, and size, there are unique factors that need to be considered when identifying potential failure modes and estimating risk.

Facilitators help the team through a PFMA and the risk analysis process. The facilitator contributes to the process by bringing experience with risk analysis, consistency in approach, knowledge of latest technology in risk analysis, and serves as a resource to the risk team for technical input and questions (BOR/USACE, 2015). The facilitator must be experienced and generally familiar with most aspects of dam design, construction, and behavior. In addition, skills are needed to guide a team through the process. Facilitation is a critical part of the process to develop credible risk estimates.

The facilitators are primarily tasked to ensure appropriate risk methodologies are followed to develop risk estimates; the methods used during the risk analysis meeting are consistent with current practice; alternative viewpoints are elicited, discussed, and recorded; the team contains the appropriate staff to arrive at a credible risk estimate; the final risk analysis report contains potential failure modes that are adequately described; the recommendations reflect the information developed during the risk analysis; and risk analysis report adheres to the principles and guidance provided in these risk guidelines (BOR/USACE, 2015).

2.5.2.4 Heuristics and Bias

Heuristics and bias are important concepts to be aware of in conducting a risk analysis. Bias is a particular tendency, trend, inclination, feeling, or opinion, especially one that is preconceived or unreasoned. They can be systematic errors that one makes in specified circumstances. Heuristic is a simple procedure that helps find adequate, though often imperfect, answers to difficult questions - a kind of a mental and often unconscious shortcut. Both heuristics and bias can have a dramatic and negative influence in the elicitation of risk estimates. These must be recognized, and to the extent possible, the risk analysis facilitator must strive to minimize their impacts to the estimates. Vick (2002) describes many of these in detail. Some common heuristics and biases include (adapted from Kahneman, 2011):

- **Affect Heuristic** – Judgments and decisions made by consulting one’s emotions without consideration of the applicable information. (How do I feel about it?)
- **Anchoring Effect** – Occurs when one considers a particular value for an unknown quantity before developing an estimate for that quantity. Estimates then stay close to the initial number one considered. Any number that you are asked to consider as a possible solution prior to an estimate will induce an anchoring effect.

Adjustment is a deliberate attempt to find reasons to move away from the anchor. Adjustments almost always end prematurely.

- **Availability Heuristic** – The process of judging frequency by the ease with which instances come to mind.
- **Certainty Effect** – Outcomes that are almost certain are given less weight than their probability justifies.
- **Confirmation Bias** – People seek data that are likely to be compatible with the beliefs they currently hold. They favor uncritical acceptance of suggestions and exaggeration of the likelihood of extreme and improbable events.
- **Conjunctive Fallacy** – Occurs when one judges a conjunction of two events more probable than one of the events by itself.
- **Halo Effect** - A common bias that plays a large role in shaping our view of people and situations. The tendency to like (or dislike) everything about a person or situation – including things you have not observed. Increases the weight of first impressions (people, situations, information) sometimes to the point that subsequent information is wasted or ignored.
- **Hindsight Bias** – The inability to reconstruct past beliefs will cause one to underestimate the extent to which you were surprised by past events.
- **Intuitive Predictions** – These predictions are generally biased and tend to be overconfident and overly extreme. Individuals have not learned to identify the situations in which their intuition will betray them. The unrecognized limits of professional skill help explain why experts are often overconfident. Whether professionals have a chance to develop intuitive experience depends essentially on the quality and speed of feedback, as well as on sufficient experience to practice.
- **Narrative Fallacy** - Flawed stories of the past shape our views of the world and our expectations (predictions) for the future. We constantly fool ourselves by constructing flimsy accounts of the past and believing they are true.
- **Optimistic Bias** – Everything is always good. Only see the favorable side of the argument.
- **Outcome Bias** – Are influenced by the planned result or past results.
- **Planning Fallacy** – Overly optimistic forecasts of the outcome of projects. Unrealistically close to the best-case scenario (planning and cost estimating).
- **Plausibility vs Probability** - They are not equal, but some folks treat them as though they are.
- **Possibility Effect** – Causes highly unlikely outcomes to be weighted disproportionately more than they deserve.

- **Probability Neglect** – The amount of concern is not adequately sensitive to the probability of harm. You are imagining the numerator and ignoring the denominator. An example – your teenager is late getting home.
- **Probability of the Rare Event** - People overestimate the probability of rare events and overweight unlikely events.
- **Subjective Confidence** - Unrecognized limits of professional skill can lead to overconfidence in experts. The main obstacle is that subjective confidence is determined by the coherence of the story one has constructed, not on the quality and amount of information it supports. “A compelling narrative fosters an illusion of inevitability.” “Organizations that take the word of overconfident experts can expect costly consequences.”
- **The ‘Law of Small Numbers’** – A general bias that favors certainty over doubt. People are not adequately sensitive to sample size.

2.5.3 Software

Event tree analysis is a well-established method for risk analysis in the nuclear, chemical, and aerospace industries (Srivastav, 2008). It has also become a common approach for dam safety risk analysis. For more information on event tree construction, see *Best Practices for Dam and Levee Risk Analyses* (BOR/USACE, 2015).

To facilitate event tree analysis, several risk software tools have been developed. In the United States, two primary risk software tools have been used: DAMRAE and Palisade’s Decision Tools Suite (that includes Precision Tree and @Risk). Each of these tools has advantages as well as limitations. Internationally, other risk software tools have also been used.

No single risk software tool is required by the FERC to perform the computational functions of a risk analysis. Risk software tools need to be able to perform the required calculations properly and inputs and outputs need to be clearly identified and documented. It is highly recommended that the risk software being proposed for the risk analysis be discussed with the FERC prior to initiating any risk analysis work.

2.5.4 Methodology

2.5.4.1 General

FERC is responsible for the development, dissemination, and interpretation of methodology guidance for use in conducting dam safety risk analyses. As the state of the practice for risk analysis continuously evolves and improves, the FERC should be contacted for the most current risk analysis guidance. The *Best Practices for Dam and*

Levee Risk Analyses has been developed jointly between the USACE and the BOR for the purpose of summarizing the overall philosophy, methods, and approach to risk analysis for dam safety (BOR/USACE, 2015). The BOR/USACE ‘Best Practices’ manual is generally maintained and updated on an as needed basis. The current version of the ‘Best Practices’ manual may be obtained from BOR (refer to web link in references) or from the USACE. Unless otherwise directed by FERC, the risk teams should use the ‘Best Practices’ manual to guide their efforts in determining the loads, the conditional probability of failure associated with each failure mode, and the consequences associated with each potential failure mode.

The methodology contained in the ‘Best Practices’ manual provides a suite of scalable analysis approaches that provide information to promote critical thinking and guide a risk analyst’s (facilitator or subject matter expert) judgment. These methods are scalable and can be applied with varying degrees of effort (time and cost) to provide the appropriate level of accuracy and rigor required to make credible risk estimates. It is important to understand that every decision does not require a high level of rigor, detail, and accuracy in the risk estimate in order to support a credible decision.

Risk teams and those that are responsible for conducting risk analyses are accountable for understanding the methodology, making and documenting credible and transparent decisions on key input parameters, explaining why the results either do or do not make sense, and adjusting the risk estimate accordingly (USACE, 2014). This will require some judgment and team elicitation to translate the results obtained from the risk methodologies and other likelihood factors to a logical risk estimate. The risk analysis team must apply an understanding of the potential failure modes, key factors, uncertainties, and sensitivities to obtain a risk estimate that they are willing and able to defend with a set of logical arguments.

All risk estimates must include due consideration for intervention. Intervention includes those actions that can lead to preventing a breach from occurring or mitigating the consequences of a breach (USACE, 2014). Successful intervention requires taking actions to detect a developing potential failure mode and then taking actions to arrest further development of the potential failure mode. Risk estimates should include with and without intervention scenarios, as appropriate. It is important to understand the potential benefits of intervention while at the same time not masking the potential seriousness of a dam safety issue by using intervention to reduce the estimated risk.

2.5.4.2 Quantitative Risk Estimates

Risk estimates for significant potential failure modes (those potential failure modes that contribute to the total risk, including those potential failure modes that have the ability to result in intolerable risks) are to be portrayed in the form of the mean estimate of risk (expected value), whether it is individual potential failure mode estimates or total risk,

and the range (distribution) about the mean that includes due consideration of the uncertainty of the estimate.

2.5.4.3 Uncertainty Framework

Uncertainty is the result of imperfect knowledge about the present or future state of a system, event, situation, or population under consideration (FEMA, 2015). Uncertainty is used to portray variability or a range of values for loads, consequences, conditional response estimates, and risk estimates, rather than a single point estimate for those values.

At the simplest of levels, two main groups of uncertainty exist; these are aleatory (or stochastic) and epistemic (or knowledge-based) uncertainty. The most important distinction between these two types of uncertainty, at a practical level, is that the knowledge-based uncertainty may be reduced by further study, should a reduction in the overall uncertainty in the results from an analysis prove necessary. The aleatory uncertainty, on the other hand, is by definition irreducible.

All risk estimates must give due consideration of uncertainty. This can be accomplished either qualitatively or quantitatively depending on the needs of the risk assessment.

The quantification of risk estimates is dependent on available data and analyses regarding the design, construction, performance and current condition of a dam. It also depends on the identified loads that the dam could be subjected to over its operating life and knowledge about how the downstream population would be affected by a flood resulting from a dam breach. It is acknowledged that the quantification of risk estimates includes a degree of subjectivity regardless of how the estimates are made, and is a function of group dynamics, the experience and associated judgment of group members, models used in the analyses, and the available information for a dam. Thus, uncertainty in the risk estimates is expected. This uncertainty is typically captured by assigning ranges to probability and consequences estimates.

Key areas of uncertainty are to be identified and their potential effect on the risk estimate and resulting decisions presented.

2.5.4.4 Confidence

An assessment of the confidence the risk team has for each risk estimate should be documented for each nodal probability or risk estimate made by the team. Confidence is a qualitative measure of belief that the information, engineering analysis results, and risk estimate is reasonable (BOR, 2011). Confidence is used to describe how sure the risk analyst/team is about the risk estimate.

Factors that influence confidence include:

- Quantity and quality of the information available
- Representiveness of the information
- Information/analysis results accurately capture the expected performance

When assigning confidence descriptors, the reasoning behind the descriptor, and the information that could be gathered to improve the rating should also be captured in the documentation. Examples of confidence statements include:

- “Given a known diverse and heterogeneous foundation material that is characterized by limited borings of questionable quality, the risk team had a low confidence in the probability of a foundation flaw estimate.”
- “The plethora of high quality test data indicated a wide range in unconfined compressive strengths of the concrete. Although the range is large, there is high confidence in the data and the resulting risk estimates.”

Care must be taken so as not to confuse confidence with uncertainty. One can be highly confident that there is a small range of uncertainty.

2.5.4.5 Sensitivity

Sensitivity is a measure of how much risk estimates change when key input assumptions (i.e. nodal risk estimates) are varied (BOR, 2011). This is characterized by performing sensitivity analyses, varying the probability of variables that most affect the outcome of the risk analysis, and examining the resulting effects on the risk estimates.

Sensitivity studies should be used to assist in defining ranges of uncertainty of risk estimates. In addition, results from sensitivity studies should be used to judge the relative “confidence” in risk estimates and/or resulting conclusions. For example, if parametric studies indicate a relatively minor difference in estimated risks, there would be confidence in the risk estimates. Conversely, if varying the parameter over a reasonable range results in a significant change in potential risks or conclusions, there would be less confidence.

Risk analysis results that include sensitivity studies should provide information on what would happen if more information was gathered, and whether the information is important (USACE, 2014). Plausible and reasonable upper and lower bound values for variables in question should be chosen and processed. When this test causes the perceived risk to change significantly and confidence in the expected value is not high, action or additional studies may be warranted to obtain additional information. A change is significant if it changes the risk tolerability or decision. Additional reasoning to show why the upper or lower bound values are plausible and reasonable is necessary to support

a recommendation for acquiring additional information and why the additional information being requested is likely to reduce the uncertainty.

2.5.4.6 Combining Risks

After all potential failure modes have been identified, described, and evaluated relative to the risk they pose, the results need to be combined so that the technical reviewers and decision makers can understand and act upon them (FEMA, 2015). This requires some attention to detail, which if not undertaken properly, can result in an improper portrayal of the risk. During Level 4 risk analyses, estimates of risk are generated for individual potential failure modes. These estimates include probability or risk values for different loading conditions, loading ranges, potential failure modes, spatial segments, or other situations. Not only do the individual estimates result from an aggregation of their own constituents, but they themselves are often combined in some way to express their collective effect. Independence is an important concept when evaluating and combining risks. In practice, the most common problems encountered during risk analyses are related to systems, correlations, common-cause loading, and combining risks. Although the methods to evaluate these issues can be complex, some simplifications can be applied to situations commonly seen when evaluating risks for dams. The ‘Best Practices’ manual provides the details on how to properly combine risks (BOR/USACE, 2015).

2.5.5 As-Low-As-Reasonably-Practicable (ALARP)

2.5.5.1 General

ALARP is a principle that states that risks, lower than the tolerable risk reference line, are tolerable only if risk reduction is impracticable or if the next increment of risk reduction is not cost effective compared to the improvement gained (USACE, 2014, revised from ICOLD, 2005). The answers to the questions: “When are risks low enough?” “What actions are reasonable?” and “What actions are practicable?” are key ALARP risk considerations that require subjective judgment (USACE, 2014). These considerations provide a way to address efficiency in reducing risks.

The general ALARP concept is that risk reduction beyond a certain level may not be justified if further risk reduction is impracticable or if the cost is grossly disproportionate to the benefits obtained by the risk reduction. This is graphically illustrated in Figure 2-7. ALARP only has meaning in evaluating risk reduction measures – it cannot be applied to an existing risk without considering the options to reduce that risk. Consideration of ALARP is a matter of judgment.

Judgments are required to make an assessment regarding tolerable risk. Tolerable risk, as defined by ICOLD (2005) and adapted from HSE (2001a) is, “a risk within a range that society can live with (1) so as to secure certain net benefits. It is (2) a range of risk that

we do not regard as negligible or as something we might ignore, but rather as something we need to (3) keep under review and (4) reduce it still further if and as we can.” Each of these conditions has implications for dam safety (Bowles, 2007).

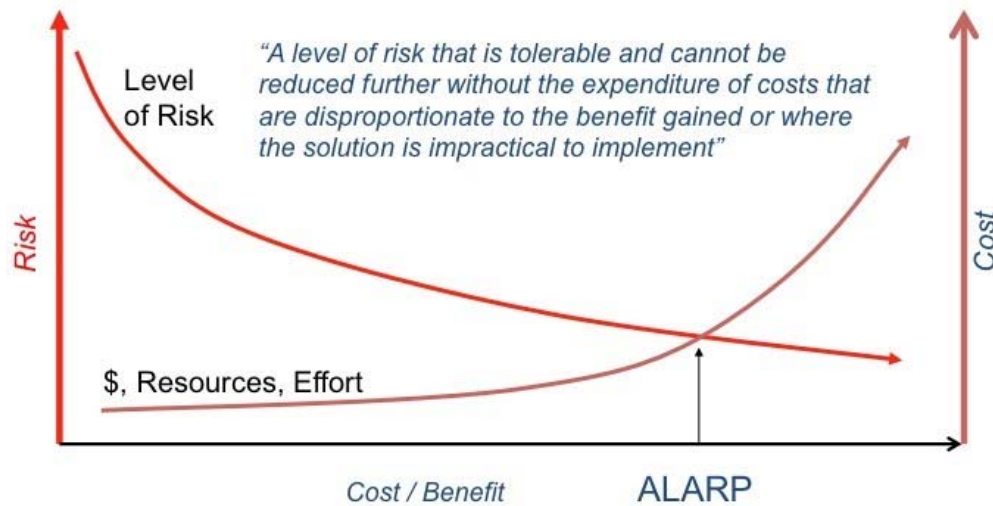


Figure 2-9. Graphic Illustration of ALARP. (Talbot, 2015)

The ALARP principle is represented as condition (4) in the paragraph above.

ALARP requires a range of options for risk reduction to be considered. For a risk to be ALARP it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained (Victoria DSE, 2012).

Unfortunately there is no mathematical formula or ‘seven-step process’ available to determine ALARP. Instead, there are a number of factors that must be evaluated and considered to judge ALARP. To make a judgment on whether risks are ALARP, the following factors must be considered (adapted from NSW, 2010):

- The cost-effectiveness of the risk reduction measures;
- The level of risk in relation to the tolerable risk guidelines;
- The disproportion between the sacrifice (money, time, trouble and effort) in implementing the risk reduction measures and the subsequent risk reduction achieved;
- Any relevant recognized good practice; and
- Societal concerns as revealed by consultation with the community and other stakeholders.

Each of these factors is discussed in the following sections.

ALARP is a requirement of Level 4 risk analyses. ALARP, in a qualitative sense, can be evaluated in Level 2 or 3 risk analyses when trying to build the case for why risk results are ‘tolerable’. See Chapter 3 for more discussion on what constitutes ‘tolerable’ risk.

Additional background and guidance on ALARP can be found in HSE 2001a, HSE 2001b, HSE 2003, HSE 2006, HSE 2008a, HSE 2008b, and HSE 2008c.

2.5.5.2 Cost Effectiveness

The cost to save a statistical life (CSSL) is a measure of cost effectiveness in achieving an increment of life safety risk reduction. CSSL is not a value placed on a human life. Adjusted CSSL, or aCSSL, is a function of:

1. Cost of the alternative risk reduction plan (\$/yr)
2. Economic consequences (\$/yr)
3. O&M costs (\$/yr)
4. Life loss (lives/yr)

The last three items in the list above are the difference between with and without implementing the alternative risk reduction plan. The aCSSL formula is shown in Appendix 2B.

A negative value of aCSSL is taken as zero.

aCSSL should be estimated for each risk reduction alternative that could reduce the risk below the tolerable risk reference line, starting at or below the tolerable risk reference line.

Assessment of aCSSL is included in Chapter 3, Risk Assessment.

2.5.5.3 Level of Risk

For individual risk and societal risks that fall below the tolerable risk reference line, the higher the risk (closer to the tolerable risk reference line shown on Figures 3-3 and 3-4 in Chapter 3), the less weight that is given to the cost of achieving risk reduction. In this context, the level of risk does not refer to the four levels of risk analysis described in these risk guidelines. Instead, the level of risk in this context refers to the value, either qualitatively or quantitatively, of the risk estimate and how high or low that value is relative to the tolerable risk reference line.

Assessment of level of risk is included in Chapter 3, Risk Assessment.

2.5.5.4 Disproportion

Disproportion is a concept used to test whether an investment in risk reduction is grossly disproportionate to the benefits that result from an avoided fatality.

Disproportionality is used as a justification to reduce the risk below the tolerable risk reference line. The disproportion between the sacrifice (money, time, trouble and effort) in implementing the risk reduction measure and the subsequent risk reduction achieved is to be evaluated using the disproportionality between the sacrifice and the risk reduction achieved. This entails the concept of "willingness-to-pay-to-prevent-a-statistical-fatality" (WTP), commonly referred by the Office of Management and Budget (OMB, 2003) and other federal agencies as the "value-of-statistical-life" (VSL) (USACE, 2014). VSL is used by OMB, the United States Department of Transportation (USDOT) (USDOT, 2014), and other federal agencies to evaluate the case for regulating risk or investing in life-saving risk reduction measures.

The risk measure for disproportionality is the ratio of the CSSL divided by WTP.

$$\text{Disproportionality ratio} = \text{CSSL}/\text{WTP}$$

The value to use for VSL is the current value used by US Department of Transportation (USDOT) (USDOT, 2014). That information is available in the US DOT report titled, "*Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses*" (USDOT, 2014). As of June 2014 USDOT uses a value for VSL of US\$9.2M. The USDOT provides annual updates of VSL.

Assessment of disproportionality is included in Chapter 3, Risk Assessment.

2.5.5.5 Good Practice

Relevant good practice is taken to be an industry consensus of what is ALARP (HSE, 2001a). Good practice is considered an upper bound to tolerable risk (HSE, 2003).

Examples of good practice (modified from Victoria, DSE, 2012) are:

- a comprehensive and robust dam safety surveillance and monitoring plan (DSSMP), including instrumentation alarm and threshold levels and notification protocols;
- a well-developed and exercised dam safety emergency action plan (EAP);
- a well-developed owners dam safety plan (ODSP) that includes:
 - practices relating to building organizational dam safety management capability and capacity through training of personnel and cross functional resource sharing and benchmarking practices;
 - routine and non-routine maintenance reviews and activities;

- leadership development and organizational resilience practices;
- adopting a “defense in depth” approach to critical operating systems;
- application of enterprise risk management, sound organizational governance and associated quality assurance; and
- routine dam safety inspections.
- up-to-date, easily accessible documentation, including key drawings and other figures/tables, on the dam and other critical structures; most recent Part 12D report and other engineering documentation in the Supporting Technical Information Document (STID);
- up-to-date engineering analyses and evaluations that provide documentation that the dam and facility meet all current FERC Engineering Guidelines.

Assessment of good practice is included in Chapter 3, Risk Assessment.

2.5.5.6 Societal Concerns

Societal concerns are defined (HSE, 2001a) as:

“...risks or threats from hazards which impact on society and which, if realised, could have adverse repercussions for the institutions responsible for putting in place the provisions and arrangements for protecting people, e.g. Parliament or the Government of the day. This type of concern is often associated with hazards that give rise to risks which, were they to materialise, could provoke a socio-political response, e.g. risk of events causing widespread or large scale detriment or the occurrence of multiple fatalities in a single event”.

HSE (2001a) further notes that hazards giving rise to societal concerns generally share a number of common features:

- They give rise to risks which could cause multiple fatalities;
- It is difficult for people to estimate intuitively the actual threat; and
- Exposure involves vulnerable groups, e.g. children, where the risks and benefits tend to be unevenly distributed.

Assessment of societal factors is included in Chapter 3, Risk Assessment.

2.5.5.7 Other Factors

There are several other factors that can assist in the assessment of ALARP. These include (from Victoria DSE, 2012):

- Duration that the risk applies – a greater focus on risk reduction may be prudent for potential failure modes associated with enduring risks compared to shorter term risks, although ANCOLD stresses that this is not necessarily the case. Short duration of risk here is not to be confused with rare events or low failure probability. In principle though, risk is expressed as an intensity (that is, as likelihood of consequences per annum) and intensity is not affected by duration.
- Availability of risk reduction options – in some situations, for some potential failure modes, it may not be possible to identify additional viable risk reduction options, thus justifying an ALARP determination. Owners will need to be mindful of technological and other developments and review this assessment periodically.
- Creation of new risks – risk reduction can itself be risky. In some cases reducing dam safety risks cannot be done without creating new and poorly understood risks. In such a situation, evaluation of ALARP may conclude that it is better to leave things as they are.
- Adequacy of the potential failure modes analysis – the determination of ALARP should be based on no less than a contemporary, thorough and expert assessment of potential failure modes. Owners will need to remain informed of any changes to the body of knowledge regarding potential failure modes, which may result in new potential failure modes being considered or modifications to event trees associated with existing potential failure modes.
- Consideration of standards based approaches – satisfaction of contemporary engineering standards may assist with justifying an ALARP determination. Having met standards, there may be additional simple, low-cost risk reduction measures that could also be considered by dam owners and managers to further reduce risk.
- Benchmarking – Very little information is available in the U.S. on benchmarking dam safety risks among dam owners. However, where benchmarking information may be available, in the form of precedents set forth by other dam owners in the literature, this information could provide helpful information about investment and rate of risk reduction, particularly as risk diminishes over time with increasing investment, and this feedback information could help inform owner investment decisions.

At a minimum, the above ALARP factors must be evaluated and clearly presented in the risk analysis report. Each ALARP factor must be considered and an overall assessment of the ALARP factors for each potential failure mode must be presented. See Section 2.6.3 for more discussion on ‘Building the Case’.

2.5.6 Documentation during the Risk Analysis

Documentation during the course of performing the risk analysis is essential. Important information, results of engineering analyses, and key factors are weighed and discussed during the course of the meeting. It is important to capture that information and discussions and document what key pieces of information influenced the subject matter experts in their risk estimates. Far too often this information is not adequately captured and weeks or months later when the risk report is being prepared, this information is long forgotten or imperfectly remembered. This contributes to weak justifications to support the risk estimates and the subsequent decisions that are needed to be made from the risk analysis.

In an effort to improve capturing this information during the risk analysis meeting and to facilitate the transfer of this information into the risk analysis report, a template has been developed that can be used by the note taker. This template and examples of its use are included in Appendix 2C.

2.6 DOCUMENTATION

2.6.1 General

The objective of the risk analysis report is to present clear, thorough, logical, and rational documentation of the analysis and results that accurately portray the risk analysis and recommended course of action in a manner and style that is to be read and understood by both the dam owner and FERC. The three basic risk components, (i.e. load probability, response probability, and consequences) should portray the dam's existing condition and ability to withstand future loading, the risk estimates, and provide the basis for the recommended actions. Since uncertainty is inherent in data, analysis, and conclusions/interpretations, the documentation should also address whether confidence is high enough for the recommendations to stand on the basis of existing evidence. The basis for the recommended actions should be documented in an objective, transparent manner, portraying the data, analysis, findings and any associated uncertainties in data or analysis on a factual basis.

A general risk analysis report outline is provided in Appendix 2D. The report outline should be revised to reflect the level of risk analysis, project-specific components, and analyses performed for the risk analysis work.

2.6.2 Content

The risk analysis report should present information regarding two main issues. Firstly, data, analysis, and conclusions should support the portrayal of risk, and secondly, the risk analysis report must substantiate the uncertainty and confidence in the risk estimates, and whether additional exploration, investigation, or analysis has a reasonable likelihood of changing the perceived risk.

It is the factual information and associated interpretation presented in the risk analysis report that determines whether the risk numbers generated and the actions recommended make sense or 'feel right' in light of an understanding of the condition of the facility and its recent history of structural behavior (USACE, 2014). For many dams, the volume of available information can be substantial. The process of sorting through this information, pulling out the most applicable data (instrument, geological, geotechnical, construction and current condition photographs, drawings, etc.) and then assimilating it into a useful and concise format is extremely important for understanding the dam and foundation characteristics and how they relate to potential failure modes.

A risk analysis report built upon sensitivity studies should investigate what would happen if more information was gathered, and whether the information is important (BOR, 2011). Plausible and reasonable upper and lower bound values for variables in question can be chosen and processed through whatever assessment is being considered. When

this test causes the perceived risk to move significantly, action may be warranted to obtain additional information. A move is significant if it changes the risk tolerability. Additional reasoning to show why the upper or lower bound values are plausible and reasonable is necessary to support a recommendation for acquiring additional information and why the additional information being requested is likely to reduce the uncertainty.

The risk report appendices are not to be a data dump. Only the pertinent information that supports the risk estimates should be included in the appendices. Including hundreds or thousands of pages of information that were not used in the risk analysis is not useful to anyone.

2.6.3 Building the Case

The dam safety case is built from a number of arguments successively demonstrated to be valid (BOR/USACE, 2015). A simple argument consists of a single claim, evidence to support that claim, and reasoning to suggest how and why the evidence justifies the claim. The dam safety case should be clearly and thoughtfully developed so that all descriptions and terms are easy to understand by the prime audience, all arguments are cogent and coherently developed, all references are easily accessible, and all conclusions are fully supported and follow logically from the arguments.

Numerical risk estimates are based on judgments, are typically subjective, and include varying degrees of uncertainty. Numerical risk estimates by themselves provide an incomplete basis for dam safety decision making (FEMA, 2015). Understanding the basis of the risk estimates is as important as or more important than the risk numbers themselves. There are a number of factors that should also be considered, including the uncertainty and confidence in the risk estimates. The dam safety case is a logical and objective set of arguments that provides supporting justification for the numerical risk estimates and is used to advocate a position that either additional safety-related action is justified or that no additional safety-related action is justified (FEMA, 2015). A well-constructed dam safety case should cite the most compelling information that supports the risk estimates and the overall findings and also discuss the uncertainties that were identified in the risk analysis.

The arguments combine together key evidence regarding the three basic risk components (load probability, response likelihood, and consequences) in order to support decisions related to a dam's existing condition or ability to withstand future loading (FEMA, 2015). The risk analysis team is in the best position to provide the supporting arguments for the risk analysis estimates. The risk analysis team should also identify a suite of options for additional actions to better define or reduce risk, if there is justification for taking actions.

Further guidance on 'Building the Case' is included in the 'Best Practices' manual (BOR/USACE, 2015).

2.6.4 Portraying Risks

Risk analysis results can be presented in a number of forms, including tables, charts, and figures. One common method includes the use of f-N or F-N charts. The usual format of these charts features a frequency of dam failure, f (also known as annual probability of failure) versus weighted average life loss, \bar{N} (f-N plot) or a cumulative frequency of N or more incremental life loss, F versus incremental life loss, N (F-N). Both axes are expressed using a log scale.

On the f-N plot, potential failure modes are usually deaggregated to provide a separate f-N pair coordinate point for each potential failure mode. Results can be aggregated in other ways to obtain estimates of the total risk, risk by load ranges, or for any other combination that is needed by the decision maker(s). The “f” values are obtained by summing the probabilities for the end branches of relevant event tree pathways. The “N” values are obtained by first summing the product of the probability and incremental consequences for the end branches of relevant event tree pathways. The resulting $f \cdot N$ value is then divided by the corresponding f value to obtain the weighted average value for \bar{N} .

On the F-N plot, the end branch probabilities are accumulated by consequence level irrespective of potential failure mode. A cumulative curve is developed and plotted showing the frequency of N or more lives lost.

Additional information is included in Risk Guidelines and Combining and Portraying Risks in ‘Best Practices’ manual (BOR/USACE, 2015).

Example F-N and f-N templates are provided in Appendix 2E.

2.6.5 Presentation of Results

Risk analysis results can be difficult to summarize and portray. Risk analysis result information can be presented in tables and on graphs depending on the type of information needing to be portrayed. Many other tables and charts can be generated depending on the type of information desired. Examples of some ways risk results and supplemental information have been presented include:

- Tables that show the contribution to risk from each potential failure mode, as shown in Table 2-3.
- Charts that show the contribution to risk from each load range.
- Charts that show the contribution to risk from reservoir elevation, as shown on Figures 2-10 and 2-11.

- Charts that show the contribution from different fault assumptions or flood assumptions (showing the value of additional hazard studies).
- Tables that summarize the nodal estimates for each potential failure mode, as shown in Tables 2-4 and 2-5.
- Charts that present the system response probabilities by reservoir elevation, including uncertainty, as shown on Figures 2-12 and 2-13.
- Charts that show the portrayal of uncertainty, as shown on Figures 2-14 and 2-15.

It is this type of information that is essential to document and present in the risk analysis report so that reviewers and decision makers can understand the results of the risk analysis. However, it is just as important to justify the results by building an adequate case.

Table 2-3. Example Summary of Annual Probability of Failure and Average Annual Life Loss for each Potential Failure Mode

Risk Driver Potential Failure Mode	APF Without Intervention	APF With Intervention
PFM 1 – IE into Rock Foundation (ICOS Wall Section)	1.29E-07 (1%)	2.32E-08 (0%)
PFM 2 – IE into Rock Foundation (Beyond ICOS Wall)	2.88E-07 (2%)	5.26E-08 (1%)
PFM 3 – Concentrated Leak Erosion at Right Abutment	2.88E-06 (21%)	1.13E-07 (1%)
PFM 4 – Overtopping due to Gate Operational Failure	1.02E-05 (76%)	8.52E-06 (98%)
Post-Implementation Condition Total	1.35E-05 (100%)	8.71E-06 (100%)

Risk Driver Potential Failure Mode	Without Intervention		With Intervention	
	AALL	\bar{N}	AALL	\bar{N}
PFM 1 – IE into Rock Foundation (ICOS Wall Section)	6.63E-05 (1%)	515	1.38E-05 (0%)	594
PFM 2 – IE into Rock Foundation (Beyond ICOS Wall)	7.68E-05 (1%)	267	1.72E-05 (0%)	326
PFM 3 – Concentrated Leak Erosion at Right Abutment	2.74E-04 (3%)	95	1.51E-05 (0%)	134
PFM 4 – Overtopping due to Gate Operational Failure	8.02E-03 (95%)	785	6.53E-03 (99%)	766
Post-Implementation Condition Total	8.44E-03 (100%)	624	6.57E-03 (100%)	755

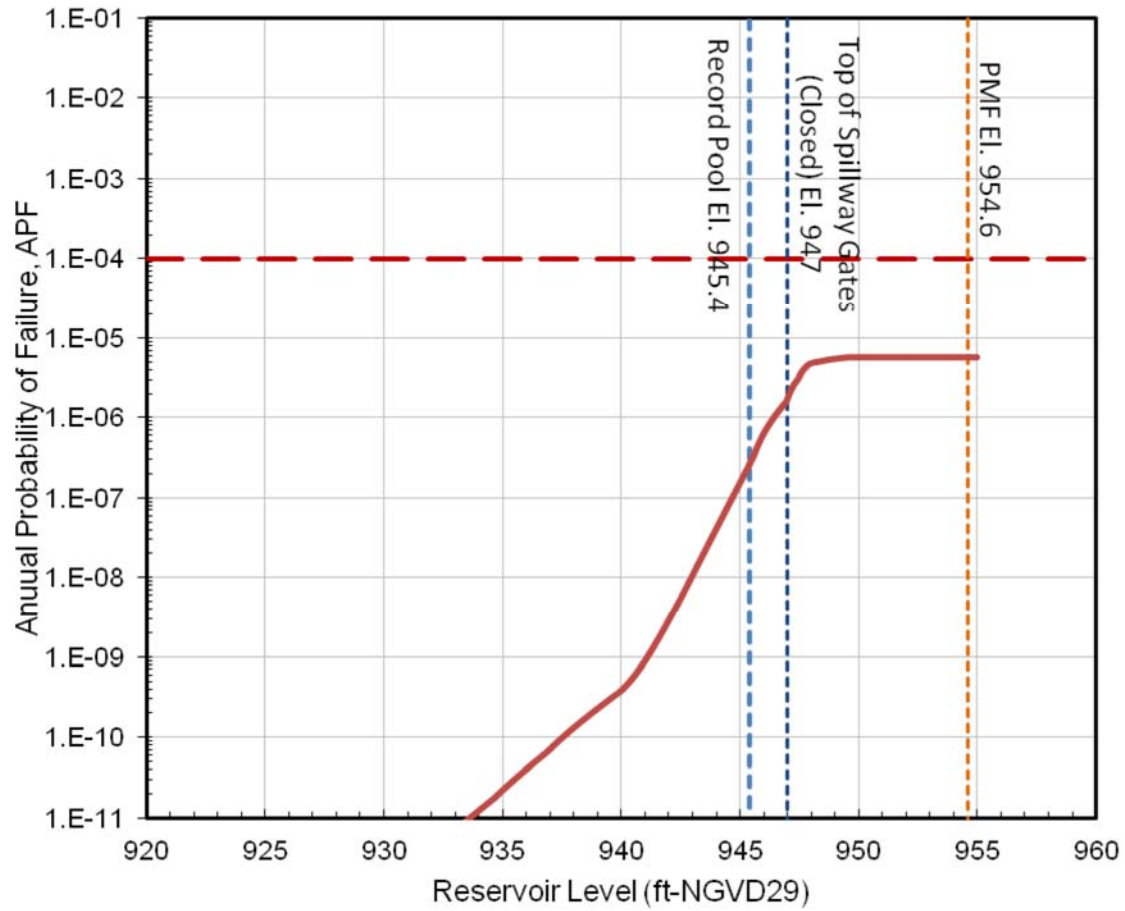


Figure 2-10. Example of Contributions to Annualized Probability of Failure by Reservoir Elevation

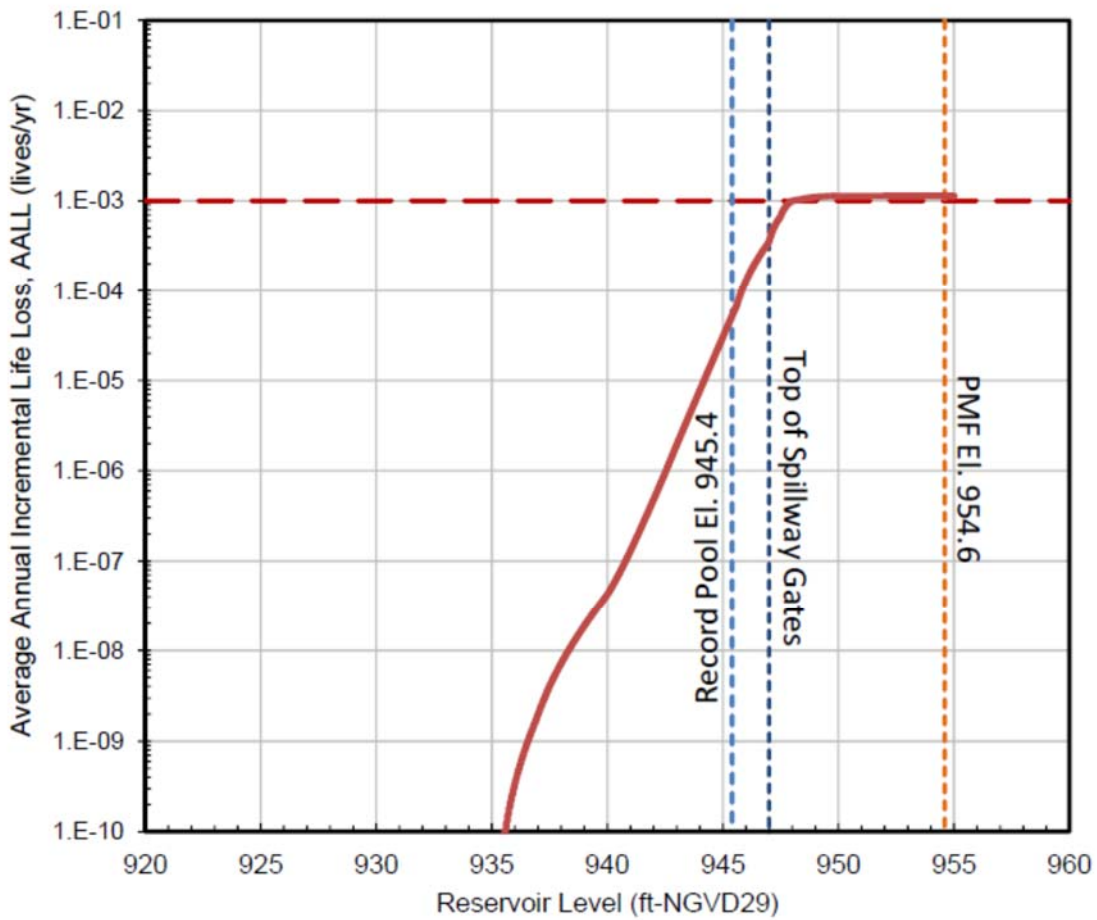


Figure 2-11. Example of Contributions to Average Annual Life Loss by Reservoir Elevation

Table 2-4. Example of Summarizing Nodal Probabilities

Pool Elev. (ft-NGVD29)	Node 1 Flaw	Node 2 Initiation	Node 3 Unfiltered Exit	Node 4 Progression (Crack open)	Node 5 Progression (Flow Limiter)	Node 6 Progression (Crack Filling)	Node 7: Intervention	Node 8: Breach
920	0.1	0.00001	0.999	0.99	0.999	0.95	0	0.0000001
940		0.001					0.1	0.01
945.4		0.1					0.3	0.5
947		0.2					0.6	0.75
947.5		0.25					0.6	0.75
949		0.52					0.85	0.9
954.2		0.8					0.95	0.99
957		0.9					0.99	0.999

Table 2-5. Example of System Response Summaries by Reservoir Level

Pool (ft-NGVD29)	SRP (without intervention)	SRP (intervention considered)
920.0	9.39E-14	0.00E+00
940.0	9.39E-07	2.35E-07
945.4	4.69E-03	2.35E-03
947.0	1.41E-02	9.86E-03
947.5	1.76E-02	1.41E-02
949.0	4.39E-02	4.17E-02
954.2	7.43E-02	7.36E-02
957.0	8.44E-02	8.43E-02

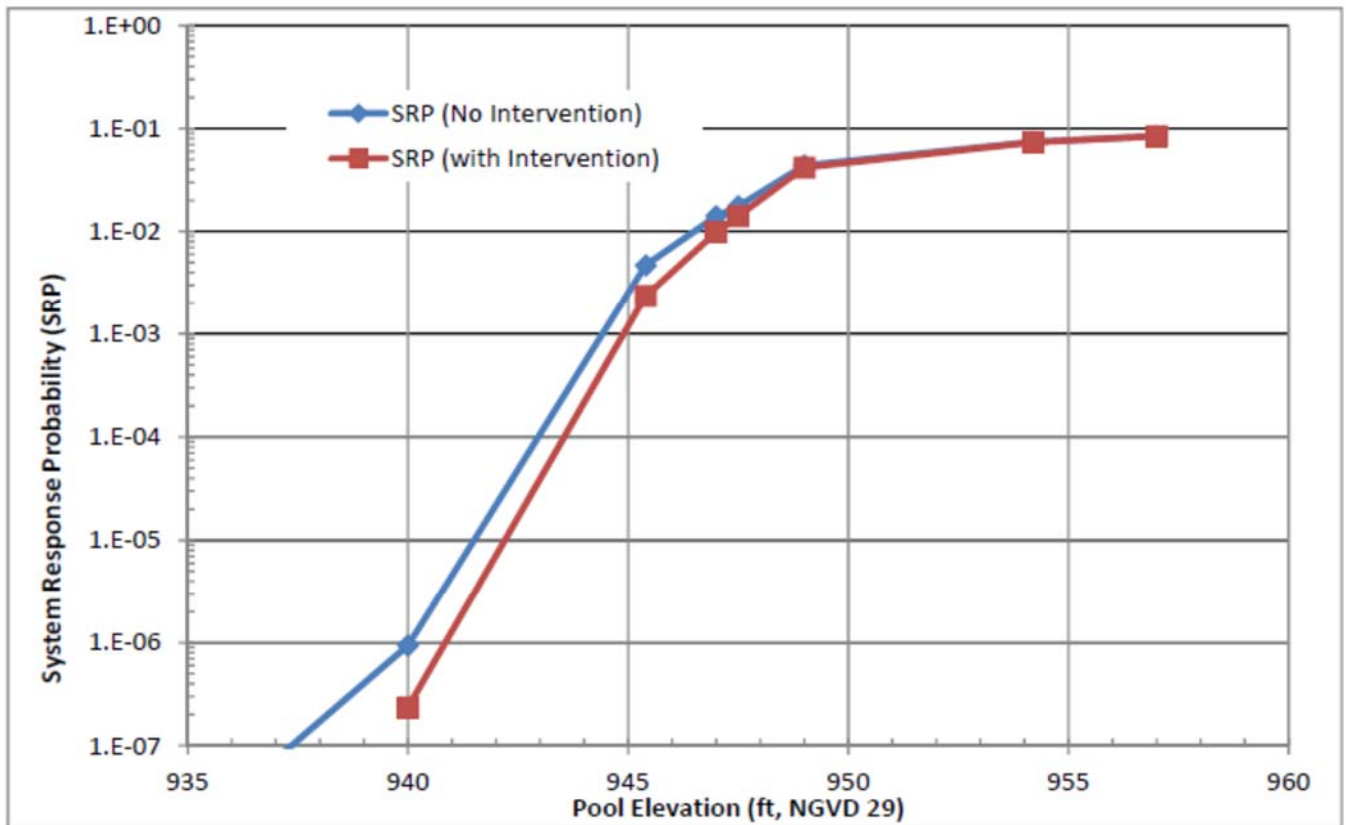


Figure 2-12. Example System Response Probability by Reservoir Elevation

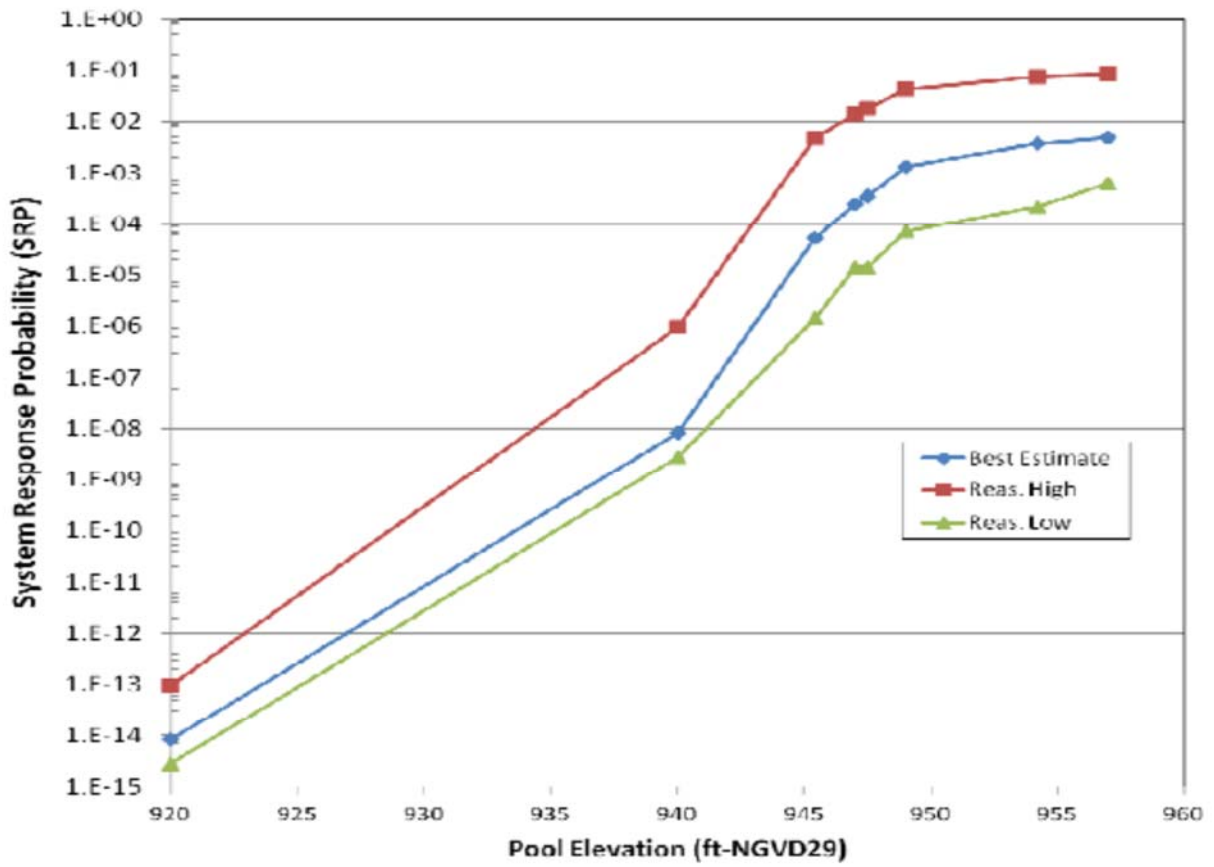


Figure 2-13. Example System Response Probability with Uncertainty by Reservoir Elevation

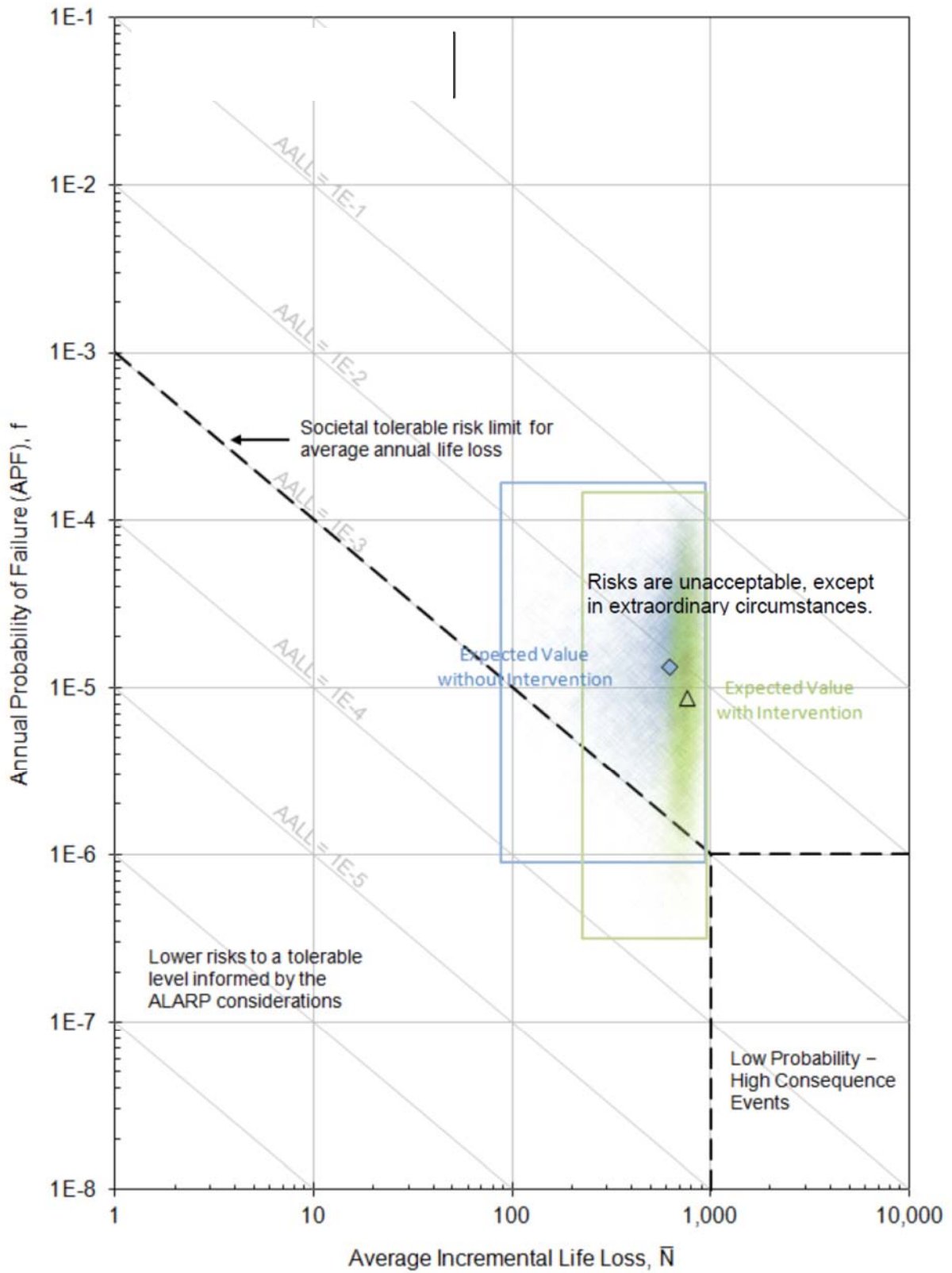


Figure 2-14. Example f-N Chart Portraying Uncertainty

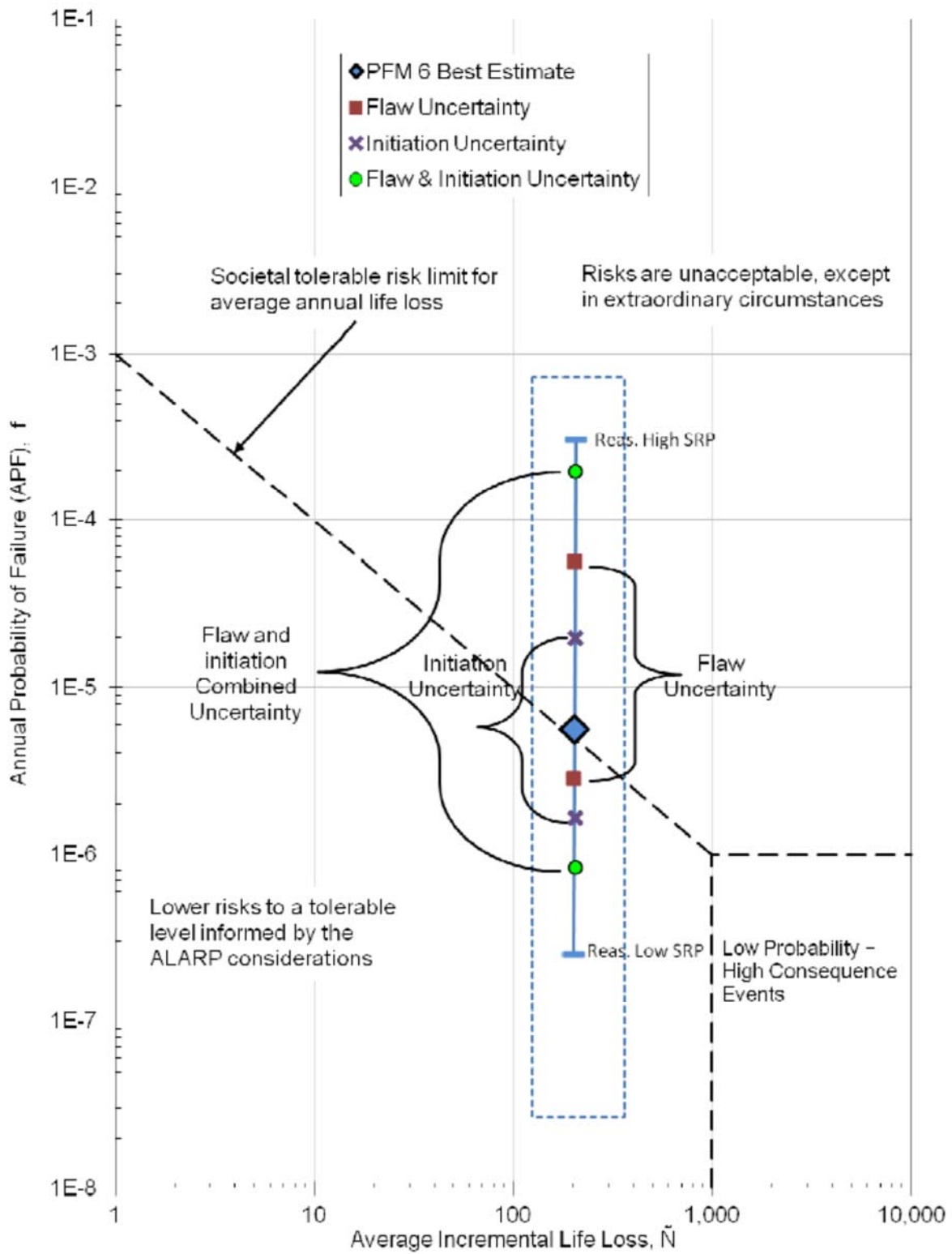


Figure 2-15. Example f-N Chart Portraying Specific Nodal Uncertainty for an Individual Potential Failure Mode

2.7 REVIEWS

2.7.1 General

Review requirements are commensurate with the complexity, outcomes, and decisions of the risk analysis. Five copies of the risk analysis reports and products shall be submitted to the FERC Regional Engineer for review and acceptance.

FERC encourages the use of peer review throughout the duration of the risk analysis work, including the development of the initial scope of work.

2.7.2 Level 2 – Periodic Risk Analysis Products

Review of Level 2 risk analysis products will be performed by FERC-D2SI staff. It is anticipated that this review will be performed in conjunction with the review of the associated Part 12D report. Review comments, if necessary, will be provided to the Licensee for resolution and resubmittal, as appropriate. FERC acceptance of the Level 2 risk analysis products will be provided after resolution of all FERC comments.

2.7.3 Level 3 – Semi-Quantitative Risk Analysis Products

Review of Level 3 risk analysis products will be performed by FERC-D2SI staff. Review comments, if necessary, will be provided to the Licensee for resolution and resubmittal, as appropriate. FERC acceptance of the Level 3 risk analysis products will be provided after resolution of all FERC comments.

2.7.4 Level 4 – Quantitative Risk Analysis Products

Review of Level 4 risk analysis products will be performed by FERC-D2SI staff and will be supplemented with a Risk Review Board (RRB). A RRB will be comprised of select, highly-qualified individuals in various dam safety specialties that also have significant knowledge and expertise in risk analyses for dam safety projects and risk-informed decision making.

2.7.4.1 Risk Review Board (RRB) Members

RRB members will be charged with reviewing the draft risk report, providing draft review comments, attending a RRB meeting, and providing final review comments.

The FERC will develop and maintain a list of approved RRB members that licensees can select from. In general, RRB panel members must meet the minimum qualifications of a sublevel 4C risk facilitator shown in Table 2-2.

Technical disciplines generally used to serve as RRB members may include, but not be limited to, the following:

- Geotechnical engineer
- Structural engineer
- Hydrologist
- Seismologist
- Hydraulic engineer
- Civil engineer
- Engineering geologist
- Rock mechanics specialist
- Consequence specialist
- Economist
- Cost estimator/Constructability specialist
- Emergency management specialist
- Risk analysis specialist

RRB members are considered a specialist in their particular field of expertise. Many of the technical disciplines listed above cover a broad range of subjects and associated potential failure modes. For example, a geotechnical engineer may specialize (with regards to dam safety) in internal erosion, seismic deformation/liquefaction, rock mechanics, or other areas. Therefore, an approved RRB member who is a geotechnical engineer that specializes in internal erosion may not have the requisite qualifications to serve as a RRB member for risk analyses dominated by seismic or liquefaction potential failure modes.

The estimated number of RRB members for each risk analysis report is included in Table 2-6. The actual number of RRB members and the associated technical disciplines will be determined by the FERC and will be based on the complexity of the project and the technical issues being evaluated by the risk analysis.

Table 2-6. Estimated Number of Risk Review Board (RRB) Members

Level of Risk Analysis	Type of Risk Analysis	
	Existing Conditions Risk Analysis	Risk Reduction Risk Analysis
Sublevel 4A	2 to 3	3 to 4
Sublevel 4B	2 to 4	3 to 5
Sublevel 4C	2 to 4	3 to 5

The FERC will require the licensee to coordinate and contract for the RRB members.

It is the stated expectation that RRB members will have sufficient time to review the draft risk analysis report and the appropriate supplemental project documents. In an effort to better define those expectations, general minimum review time guidance for each RRB member is provided in Table 2-7.

Table 2-7 – Estimated Risk Review Board (RRB) Minimum Review Time

Level of Risk Analysis	Estimated Minimum Review Time for Each Risk Review Board (RRB) Member
Sublevel 4A	24 hours
Sublevel 4B	30 hours
Sublevel 4C	36 hours

The estimated minimum review times included in Table 2-7 are for the review of the draft risk analysis report and the supporting documentation. It is expected that the estimated review times will vary depending on the complexity of the risk analysis, number of potential failure modes carried forward in the risk analysis, and other factors. The estimated review times in Table 2-7 do not include additional RRB efforts for other project activities that include preparation of written draft and final review comments, travel and attendance at the RRB meeting, contracting activities, etc.

2.7.4.2 Risk Product Review Process

The following is a general sequence of the Level 4 risk product review process:

- The Licensee submits the draft risk analysis report to the FERC and RRB members a minimum of 60 days prior to the RRB meeting.
- The RRB members review the Licensee-submitted draft report and accompanying project documents and submit written draft review comments directly to the FERC and the Licensee a minimum of 30 days prior to the RRB meeting.
- The Licensee submits the draft RRB meeting presentation and proposed meeting agenda to the FERC a minimum of 14 days prior to the RRB meeting. The FERC reviews the draft risk presentation and proposed meeting agenda and provides written comments to the Licensee no later than 5 days prior to the RRB meeting. An example meeting agenda is included in Appendix 2F.
- RRB Meeting and Risk Presentation. The RRB Meeting and Risk Presentation is held at the FERC Regional Office, FERC Headquarters Office, or mutually agreed upon office location. The meeting is attended by the Licensee, the risk analysis facilitator, and other significant risk team members as needed, the FERC

representatives, and the RRB members. A representative from the FERC, or their designated alternate, will facilitate the RRB meeting.

- Final comments from the RRB members are submitted directly to the FERC and the Licensee within 14 days from the date of the RRB meeting.
- The FERC will compile internal and RRB final review comments into a letter and transmit the overall review comment letter to the Licensee.
- The Licensee will review the FERC's review comment letter and address the review comments in a revised report. The revised report shall include an appendix that lists each comment included in the FERC review letter and how and where in the report the Licensee (or consultant) addressed each comment.
- The Licensee submits the revised report to the FERC for further review.
- The FERC reviews the final report and transmits an acceptance letter to the Licensee.

The charge questions for the RRB for both existing conditions risk analyses (issue evaluation studies) and risk reduction risk analyses (dam safety modification studies) are included in Appendix 2G. The RRB members are required to submit their individual draft and final report review comments directly to the FERC and the Licensee. The Licensees contract(s) with the RRB members should explicitly include this provision. The RRB members may or may not choose to collaborate during their review of the risk products prior to the RRB meeting. As the RRB members generally serve in different technical disciplines and each have unique experiences, the RRB members do not have to reach consensus. As such, the RRB members draft and final comments are considered advisory (non-binding) to the FERC and the Licensee.

In highly complex, innovative approaches, technically challenging, or politically sensitive projects, the FERC may require a separate RRB for the loadings (seismic and hydrologic) and consequences, particularly if these factors have greater significant influence on the overall results of the risk analysis and potential decision from the risk assessment. Review of the loadings is strongly encouraged to take place well in advance of the risk analysis.

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APPENDICES

APPENDIX 2A

EXAMPLE RISK ANALYSIS MEETING AGENDA

Typical Risk Analysis Meeting Agenda

1. Introduction of team members and their responsibilities
2. Quick reviews of:
 - a. Dam
 - b. Geology
 - c. Appurtenant structures
 - d. Instrumentation data
 - e. Operations of the reservoir and dam
 - f. Flood routings
 - g. Seismicity
 - h. What's downstream
 - i. Existing known dam safety deficiencies
3. Discuss and identify potential failure modes
4. Develop event trees for credible potential failure modes, as appropriate
 - a. Develop load ranges, where applicable
 - b. Develop probability estimate distributions for each node
 - c. Review team's estimates
5. Develop or review loss of life estimates
 - a. Population at risk
 - b. Warning time estimates
 - c. Loss of life
6. Review risk analysis calculations and results
7. Discuss presentation of the results, the conclusions reached, and the recommended actions, as available. As part of this discussion consider the following questions:
 - a. What potential failure modes create the highest risk?
 - b. What load range increments are associated with the highest estimates?
 - c. What are the uncertainties for the highest risk?
 - d. What data or analysis would reduce the uncertainty?
 - e. What is the anticipated range of results from gathering more data/performing more analysis?
 - f. How would these outcomes impact risk?
 - g. Where do we go? What will it cost?
8. Discuss 'building the case' for the risk estimates and the path forward
9. Set future schedules
 - a. Draft report sections written
 - b. Review
 - c. Next meeting to discuss final results
 - d. Draft report
 - e. Report review
 - f. Final report

APPENDIX 2B

**CALCULATION OF THE ADJUSTED COST TO SAVE A STATISTICAL LIFE
(aCSSL)**

CALCULATION OF THE ADJUSTED COST TO SAVE A STATISTICAL LIFE (aCSSL)

The aCSSL is calculated as follows:

$$\text{aCSSL} = \frac{\text{AC} - (\text{EC}_{\text{w/o}} - \text{EC}_{\text{w}}) - (\text{OM}_{\text{w/o}} - \text{OM}_{\text{w}})}{(\text{AALL}_{\text{w/o}} - \text{AALL}_{\text{w}})}$$

Where,

aCSSL = cost to save a statistical life (\$/life), where a negative value is taken as zero

AC = average annual cost of the alternative risk management plan (\$/yr)

$\text{EC}_{\text{w/o}}$ = average annual economic consequences (\$/yr) without alternative risk management plan.

EC_{w} = average annual economic consequences (\$/yr) with alternative risk management plan.

$\text{OM}_{\text{w/o}}$ = average annual O&M cost (\$/yr) without alternative risk management plan.

OM_{w} = average annual O&M cost (\$/yr) with alternative risk management plan.

$\text{AALL}_{\text{w/o}}$ = average annual life loss (lives/yr) without alternative risk management plan.

AALL_{w} = average annual life loss (lives/yr) with alternative risk management plan.

Notes:


1. Evaluations of alternative risk management plans should be based on values (lives lost, costs, benefits, etc.) that are representative of the time frame that is taken as the economic life of the project or feature under study.


APPENDIX 2C

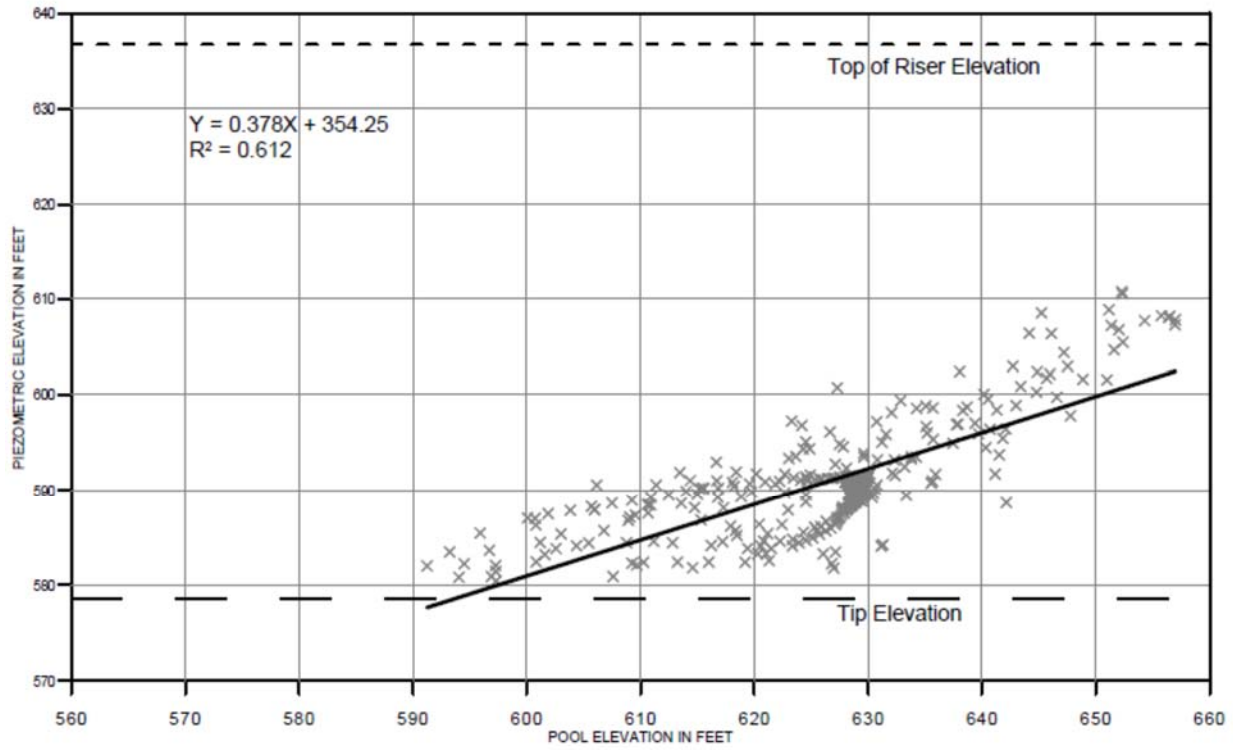
RISK ANALYSIS MEETING TEMPLATE AND EXAMPLE

EXAMPLES

Event Information		
Loading Condition:	Flood Loading	
Failure Mode:	Piping along the outlet works conduit due to a void	
Location:	Core/Outlet works	
Event:	Pool ranges evaluated (ft. NGVD29): Min. Conservation-620, 620-658, 658-690.4 (PMF)	
Event Tree Node:	Flaw Exists	
Estimates and Distributions		
Elevation	Most Likely Estimate	Team Consensus
Minimum Conservation – 620 (620)	0.01, 0.01, 0.01, 0.1, 0.01, 0.05, 0.005, 0.01	0.01
620 – 658 (638)	0.01, 0.05, 0.05, 0.1, 0.01, 0.05, 0.005, 0.04	0.05
658 – 690.4 (690.4)	0.05-0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.01, 0.08	0.1
Key Statement:	Lean concrete placed (As-Constructed drawings) as backfill fills the narrow portion of the trench and provides a wide surface for compaction of the core. Good quality of construction and inspection. Wide space reduces potential arching of the core. It appears that the exiting seepage is associated with flow through the abutment.	
Confidence:	High because of As-Constructed drawings.	
Influence Factors		
Likely	Unlikely	
Construction photos do not clearly show lean concrete backfill as shown on typical cross-section (as-built).	Lean concrete placed as backfill a bit above the springline from upstream through downstream from middle of core (sta. 10+00) downstream for 60' (Reference Sheets 162/51.2 and 162/5.4, as-constructed drawings; left side sta. 9+96.5, right side sta. 10+02.8 to sta. 10+63.5. Sketches located at end of this section).	
Used hand tamping above the lean concrete placed as backfill. In this area, there were two cutoff collars that had to be compacted around	Lean concrete placed as backfill eliminated the compaction in the narrow portion of the trench and allowed access for compaction.	

	
<p>Arching effects reduce lateral stresses leaving a zone that could be hydraulically fractured alongside the conduit.</p>	<p>Conditions (for arching effects) at the abutment/rock side are not as much of a concern due to widened section.</p>
<p>Highly plastic materials are difficult to compact with hand tampers and can be more compressible, more likely to arch.</p>	<p>Cutoff collars were widely spaced (20').</p>
<p>Suspect consistency of work performed over large area of hand tamping</p>	<p>Great attention paid by the contractors and inspectors to construction details.</p>
<p>Left side of conduit excavation of the core trench would be open and accessible and would not require lean mix concrete placement.</p>	
	<p>Hand compaction was not necessarily poor across the entire width of the core.</p>
	<p>No sinkholes or sloughing have been noted</p>
<p>It may be that seepage at the toe is due to a flaw in the core.</p>	<p>Seepage noted on the face of the dam is likely due to seepage out of the abutment that might saturate the shell. Given P1, P2, P3 data, as shown on geologic cross sections PDF sheet 21 of 21, downstream profile Sta. 27+00 to 17+00, marked up, it appears that seepage is originating from the through rock foundation seepage and not along the conduit; section 24-64? P3 shows no pronounced change to rise in reservoir. Plot 3-146, P-3A instrument correlation, phreatic vs. pool shows a very constant slope. Also, the gradient from P1 to P2 to P3 shows a downhill gradient toward P3, and that P1 and P2 show more response to reservoir than does P3. <Reference correlation response figures 3-142 (p1A) and 3-144 (p2A), 3-146 (p3A), located at the end of this section></p>
<p>Reservoir elevation ~617', exiting seepage begins at the cut-face area in the vicinity (toward right abutment) of the conduit.</p>	<p>The gradient from P1 to P2 to P3 A&B shows that seepage is flowing in the abutment from right to left (Piezometers were screened in rock and show strong response to reservoir pool changes and water elevations are well above tailwater) and strongly</p>

	<p>suggests the seepage source to be through rock into the embankment.</p> <p><Reference geologic cross-sections and plan view contours and piezometer plot; section on main plan map to show gradient from right to left between P1, P2 and P3; insert instrument report plots. <i>All are located at the end of the document due to image size.</i>></p>
<p>Updated photos to reference plan maps</p>	
<p>The performance above pool of record (658') is unknown.</p>	
<p>The evidence is not conclusive that all the seepage noted in the conduit area is from the rock foundation.</p>	<p>While there is seepage noted in the embankment at the toe in the conduit area, this seepage appears to be an extension of the seepage that is already occurring from the rock just downstream. <Insert updated plan view that shows seepage area. <i>Located at end of report due to image size.</i>></p>
<p>Notes</p>	
<p>None.</p>	



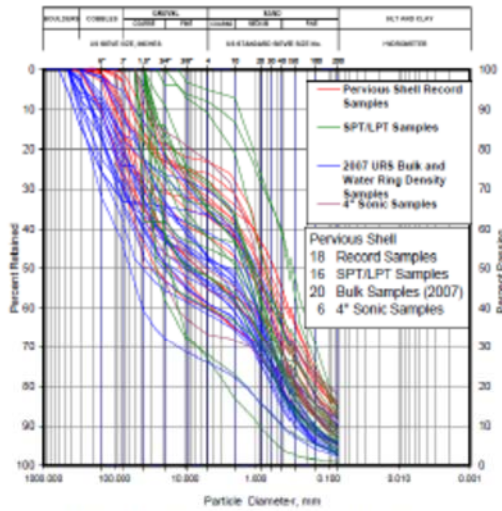


Figure C1-14. Grain Size Distribution Curves for the Pervious Shell

Unlikely that the shell will retain a continuous void from the reservoir to the core.

Construction practices show that material placed most likely would not have formed a void. Construction photos suggest that sluicing may have been performed between the conduit and the rock face to compact the material.



Permeability tests were triaxial tests, and were likely scalped.

9 record tests of pervious (shell) material indicate an average permeability of 5.9 ft/day (1966 Earth Dam Criteria Report)

Notes

None.

APPENDIX 2D
RISK ANALYSIS REPORT TEMPLATE

GENERIC TABLE OF CONTENTS

Executive Summary

- General

- Purpose of Report

- Risk Driving Potential Failure Modes

- Summary of Results

 - Incremental Risk

 - Individual Risk

 - Non-Breach Risk

 - Other Consequences

 - ALARP Considerations

- Justification of Risk Results

- Major Findings and Understandings from the Risk Analysis

- Recommendations

Chapter 1: Introduction

- Purpose

- Project Location

- Project Description

- Pertinent Project Data

Chapter 2: Background Information

- Summary of Dam Features and Components

- Regional and Site Geology

- Summary of Design and Construction

- Summary of Engineering Studies

- Post Construction Remediation

- Performance History

- Dam Operations

Chapter 3: Previous Engineering Evaluations

Chapter 4: Hydrologic Loading and Hydraulic Analyses

- Overview

- Basin Description

- Summary of Significant Floods

- Reservoir Operations Considerations

- Previous Hydrologic/Hydraulic Analyses

 - Inflow Design Flood (IDF)

- Hydrologic Analyses

 - Inputs

 - Assumptions

- Stage-Frequency Curve
- Considerations/Limitations
- Hydraulic Modeling/Analyses
 - Structure Rating Curves
 - Tailwater Rating Curve
 - Dam Break Analysis
 - Breach Location(s) and Breach Parameters
 - Hydraulic Modeling
 - Sensitivity Analyses
 - Results
 - Limitations/Considerations

Chapter 5: Seismic Loading

- Background
- Previous Studies
 - Current Maximum Credible Earthquake
- Current Seismic Hazard Assessment
 - Seismic Source Characterization
 - Ground Motion Estimates
 - Seismic Hazard Curve
 - Deaggregation
- Additional Seismic Hazard Information
 - Uniform Hazard Response Spectra
 - Time Histories
 - Vertical Accelerations

Chapter 6: Potential Failure Modes

- Summary of Previous Potential Failure Modes Analysis
- Current Potential Failure Modes Analysis
 - Approach
 - Team
 - Potential Failure Modes
 - Summary
 - Excluded Potential Failure Modes

Chapter 7: Consequences

- Study Area
- Approach
- Inundation Scenarios
- Structure Inventory
- Life Loss
 - Population at Risk
 - Warning Assumptions

- Mobilization Assumptions
- Life Loss Estimates
- Sensitivity Analyses
- Economic Consequences
- Other Consequences

Chapter 8: Risk Analysis

- Summary of Risk Driving Potential Failure Modes
- Methodology/Approach
- Team
- Risk Estimates with Justification (the case)
- Uncertainty
- Sensitivity
- ALARP
- Tolerable Risk Guidelines
- Summary of Results
 - Individual Risk
 - Societal Risk
 - Non-Breach Risk
 - Economic Considerations
 - Other Considerations

Chapter 9: Conclusions and Recommendations

- Major Findings and Understandings
- Dam Safety Case
- Interim Risk Reduction Opportunities
- Recommendations
- Risk Communication Actions

List of Appendices

- Appendix A: Pertinent Project Drawings
- Appendix B: Site Characterization
- Appendix C: Construction and Project Photographs
- Appendix D: Previous Engineering Analysis Results
- Appendix E: Hydraulics and Hydrology
- Appendix F: PSHA Report
- Appendix G: PFMA Notes and Excluded Potential Failure Modes
- Appendix H: Consequences
- Appendix I: Risk Team Elicitation Notes
- Appendix J: Risk Software Inputs
- Appendix K: ALARP Considerations/Calculations
- Appendix L: Review Documentation

APPENDIX 2E
F-N AND f-N TEMPLATES

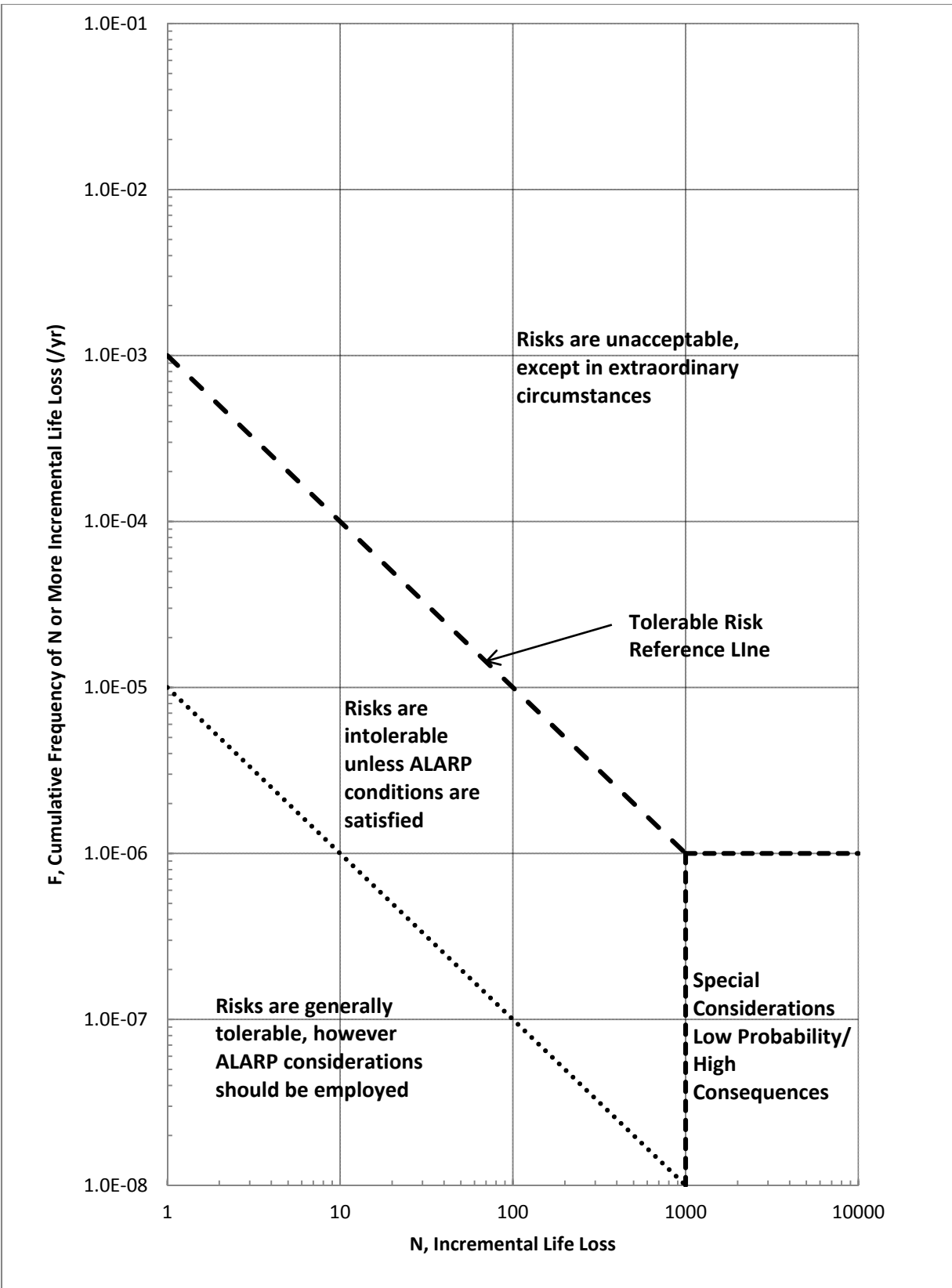


Figure 2E-1. Example F-N Plot

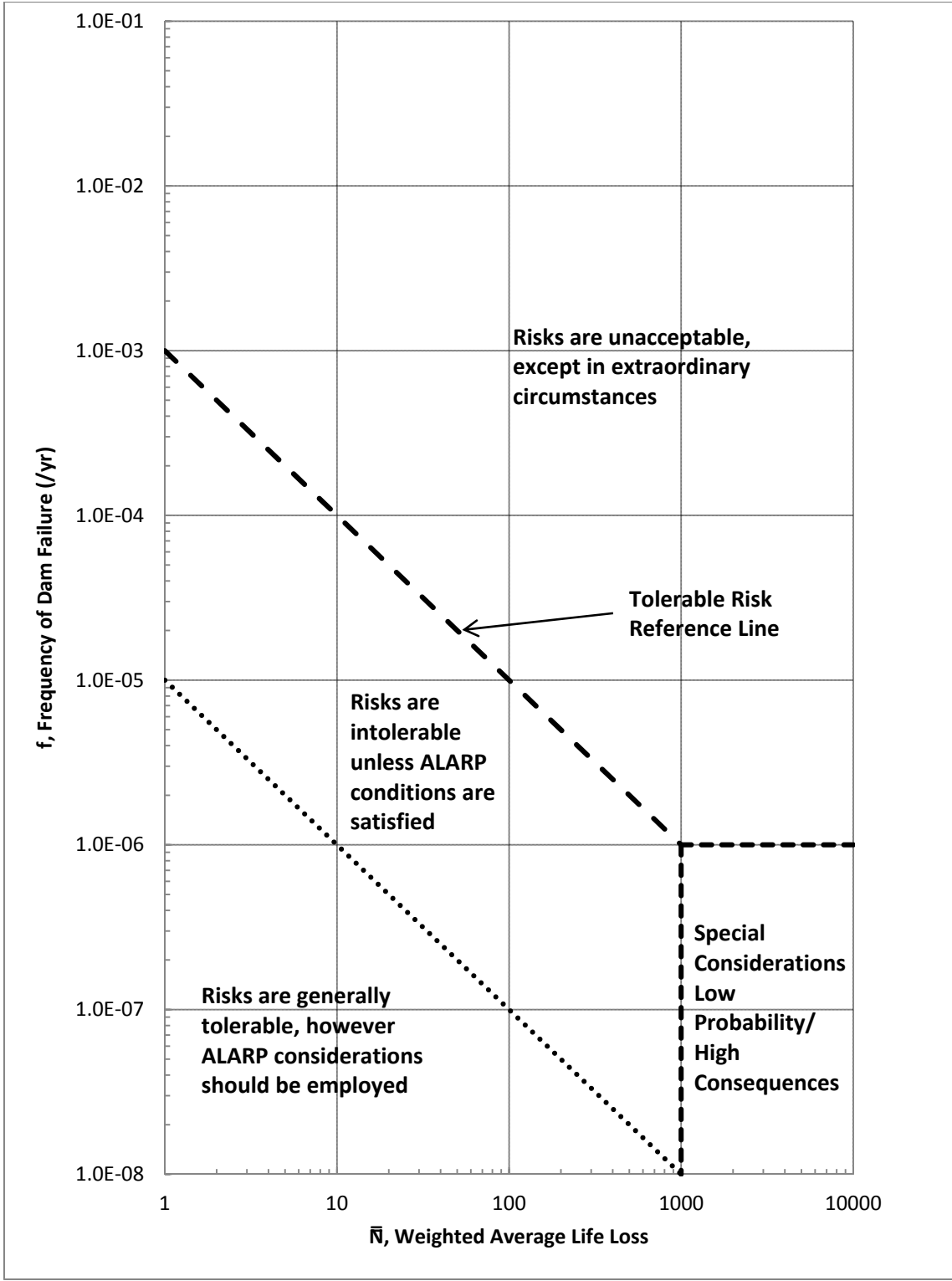


Figure 2E-2. Example f-N Plot

APPENDIX 2F

EXAMPLE RISK REVIEW BOARD (RRB) MEETING AGENDAS

Example Risk Review Board (RRB) Meeting Agenda – Existing Conditions Risk Analysis (Approximately 6 Hours)

Introduction and Project Background – 15 minutes

- General description of the facility
- Design and construction history

Regional and Project Geology – 20 minutes

Loading – 20 to 30 minutes

- Seismology
- Hydrology
- Project Operations

Potential Failure Modes – 15 minutes

- Critical (very detailed)
- Significant (detailed)
- Excluded from risk analysis (list)

Break – 15 minutes

Consequences – 15 minutes

Analysis of Risk – 60 to 75 minutes

- Critical potential failure modes
- Significant potential failure modes
- ALARP considerations

Preliminary Path Forward – 15 minutes

Discussion – 15 minutes

RRB members sequestered for internal discussions – 60 minutes

Follow up Discussions – 30 minutes

Recommended Path Forward – 10 minutes

Concluding Comments/Remarks – 10 minutes

Suggestions:

- Limit presentation to no more than 100 slides
- Bring full-size (D- or E-size) drawings
- For critical potential failure modes, provide cross-sections including:
 - Embankment zoning
 - Geology
 - Instrumentation readings with corresponding water surface
- Present inundation maps and consequences both for normal pool and extreme flood loading

Example Risk Review Board (RRB) Meeting Agenda – Risk Reduction Risk Analysis (Approximately 8 Hours)

Introduction and Project Background – 15 minutes

- General description of the facility
- Design and construction history

Regional and Project Geology – 20 minutes

Loading – 20 to 30 minutes

- Seismology
- Hydrology
- Project Operations

Potential Failure Modes – 15 minutes

- Critical (very detailed)
- Significant (detailed)
- Excluded from risk analysis (list)

Break – 15 minutes

Consequences – 15 minutes

Analysis of Risk – 60 to 75 minutes

- Critical potential failure modes
- Significant potential failure modes
- ALARP considerations (if needed)

Identification and Analysis of Risk Reduction Alternatives – 30 minutes

Evaluation of Alternatives and Selection of Preferred Alternative – 30 minutes

Preliminary Path Forward and Schedule – 20 minutes

Discussion – 30 minutes

RRB members sequestered for internal discussions – 60 minutes

Follow up Discussions – 30 minutes

Recommended Path Forward – 10 minutes

Concluding Comments/Remarks – 10 minutes

Suggestions:

- Limit presentation to no more than 125 slides
- Bring full-size (D- or E-size) drawings
- For critical potential failure modes, provide cross-sections including:
 - Embankment zoning
 - Geology
 - Instrumentation readings with corresponding water surface
- Present inundation maps and consequences both for normal pool and extreme flood loading

APPENDIX 2G

RISK REVIEW BOARD (RRB) CHARGE QUESTIONS

Risk Review Board (RRB) Charge Questions for Level 4 Existing Condition Risk Analyses (Issue Evaluation Studies):

1. Are the background, design, construction, and performance adequately explained?
2. Are the hydrologic and seismic loads adequately characterized? Was the uncertainty appropriately considered and portrayed?
3. Are potential failure modes adequately described and evaluated? Are there other potential failure modes that should be considered? Are there any potential failure modes that were excluded that should not have been? Has enough information been included for potential failure modes that were excluded from the report?
4. Are consequence estimates well supported and reasonable? Was the uncertainty appropriately considered and portrayed?
5. Are interim risk reduction measures (IRRM) reasonable? Do you suggest consideration of other IRRMs?
6. Do the portrayal and level of risks agree with your understanding of the facility's current condition and its ability to withstand potential loads, based on your review of information provided? Are risk analyses well supported and reasonable? Was the uncertainty appropriately considered and portrayed? Are there branches in risk event trees that require further evaluation, reassessment or investigation before being judged as a reasonable representation of the risk?
7. Has the team identified aspects of the load, potential failure modes, or consequences that influence the results and have they identified which items they are least confident in?
8. Have ALARP considerations been adequately evaluated? Do you suggest any other risk reduction measures be considered to evaluate ALARP? Are the estimated costs associated with the ALARP risk reduction measures appropriate and generally within current industry estimates?
9. Has the case been built for the risk estimates and recommendations? Are the risk estimates and recommendations coherent?
10. Do the recommended actions agree with the risks as they are portrayed in the documents provided for your review? If not, what actions would you recommend?
11. Do you have any other comments?

Risk Review Board (RRB) Charge Questions for Level 4 Risk Reduction Risk Analyses (Dam Safety Modification Studies):

1. Are the background, design, construction, and performance adequately explained?
2. Are the hydrologic and seismic loads adequately characterized? Was the uncertainty appropriately considered and portrayed?
3. Are potential failure modes adequately described and evaluated? Are there other potential failure modes that should be considered? Are there any potential failure modes that were excluded that should not have been? Has enough information been included for potential failure modes that were excluded from the report?
4. Are consequence estimates well supported and reasonable? Was the uncertainty appropriately considered and portrayed?
5. Are interim risk reduction measures (IRRM) reasonable? Do you suggest consideration of other IRRMs?
6. Do the portrayal and level of risks agree with your understanding of the facility's current condition and its ability to withstand potential loads, based on your review of information provided? Are risk analyses well supported and reasonable? Was the uncertainty appropriately considered and portrayed? Are there branches in risk event trees that require further evaluation, reassessment or investigation before being judged as a reasonable representation of the risk?
7. Has the team identified aspects of the load, potential failure modes, or consequences that influence the results and have they identified which items they are least confident of?
8. Has the case been built for the risk estimates and recommendations? Are the risk estimates and recommendations coherent?
9. Have reasonable alternatives to reduce the identified risks been identified and evaluated? Do you suggest consideration of other alternatives?
10. Is the selected alternative appropriate to reduce risks to tolerable levels?
11. Do you have any other comments?