FERC
Risk-Informed Decision Making Guidelines

Chapter 1

Introduction to Risk-Informed Decision Making

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ACRONYMS

ALARP.................. As Low As Reasonably Practicable

ANCOLD................ Australian National Committee on Large Dams

BOR....................... Bureau of Reclamation

DSMS.................... Dam Safety Modification Study

DSRC..................... Dam Safety Risk Classification

EAP........................ Emergency Action Plan

EG.......................... Engineering Guidelines

EMA...................... Emergency Management Agencies

FEMA.................... Federal Emergency Management Agency

FERC..................... Federal Energy Regulatory Commission

HSE........................ Health and Safety Executive, United Kingdom

ICOLD................... International Commission on Large Dams

IES......................... Issue Evaluation Study

IRRM..................... Interim Risk Reduction Measure

OMB...................... Office of Management and Budget

O&M...................... Operation and Maintenance

PFM....................... Potential Failure Modes

PFMA.................... Potential Failure Modes Analysis

RIDM..................... Risk-informed Decision Making

SBA....................... Standards Based Approach

USACE.................. United States Army Corps of Engineers

CHAPTER 1
INTRODUCTION TO RISK-INFORMED DECISION MAKING

1.1 INTRODUCTION

1.1.1 General

This chapter introduces the Federal Energy Regulatory Commission (FERC) Risk-Informed Decision Making (RIDM) Guidelines (Risk Guidelines) that will be used to identify, analyze, assess, and manage the risks associated with FERC-regulated dams. This chapter provides a brief overview and framework for the dam safety risk process. Chapter 2 provides a discussion of risk analysis and the process and procedures for conducting a risk analysis for FERC-regulated dams. Chapter 3 provides an overview of the concepts of tolerable risk and as-low-as-reasonably-practicable, how risks are to be assessed, and dam safety decision making. Chapter 4 provides a discussion on risk management, including prioritization and urgency of dam safety actions and risk communication.

1.1.2 Background

Owners, agencies, and regulators have been using risk concepts and principles for quite some time to inform decisions within various industries across the world. In particular, the United States (US), the United Kingdom (UK), the Netherlands, and Hong Kong have integrated risk principles into safety decisions in various ways since the 1960s (Ball and Floyd, 1998). In the UK, the Health and Safety Executive (HSE) was one of the first agencies over 40 years ago to broadly address individual and societal risk concerns through regulation of worker safety. Although not specifically developed for dams, the HSE risk framework provided the basis for much of today's international dam safety risk guidelines.

Those that analyze, evaluate, and manage risks have found that integrating risk approaches provide a rigorous, systematic, and thorough process that improves the quality of, and support for, safety decisions. In addition, several international entities in the dam safety industry have been using risk to inform decisions since the late 1980s. Notably, several water utilities in Australia began using the Australian National Committee on Large Dams (ANCOLD) risk management strategies to identify, assess and manage dam safety risks for their inventory of dams (ANCOLD, 2003). Both the Australian states of Victoria and New South Wales integrated many of these concepts into their regulatory framework (Victoria, 2012 and NSW, 2006).

In 1979, a committee of federal agency representatives commissioned by the President developed the *Federal Guidelines for Dam Safety* to promote prudent and reasonable dam safety practices among federal agencies (FEMA, 1979). While at the time of developing the *Federal Guidelines for Dam Safety* recognized that risk-based analysis was a recent addition to the tools available for assessing dam safety, they encouraged agencies to conduct research to refine and improve the techniques necessary to apply risk-based analysis to dam safety issues:

> *"The agencies should individually and cooperatively support research and development of risk-based analysis and methodologies as related to the safety of dams. This research should be directed especially to the fields of hydrology, earthquake hazard, and potential for dam failure. Existing agency work in these fields should be continued and expanded more specifically into developing risk concepts useful in evaluating safety issues." (FEMA, 1979).*

Nationally, both the Bureau of Reclamation (BOR) and US Army Corps of Engineers (USACE) have both implemented risk-informed processes and decision making into their dam safety programs (BOR, 2011 and USACE, 2014).

Recognizing the importance of having a consistent federal approach to managing dam safety risks, several agencies (BOR, USACE, FERC, Tennessee Valley Authority, and Federal Emergency Management Agency) began collaborating and developing general dam safety risk guidance. This work culminated with the 2015 FEMA publication *Federal Guidelines for Dam Safety Risk Management* (FEMA, 2015).

1.1.3 Approaches to Dam Safety Assessment

There are two general approaches to safety assessment of dams:

1. The standards-based approach (SBA) which is the long-standing traditional approach; and
2. The risk-informed decision making (RIDM) approach which has a long history in the process industries, but has only recently been applied to dams.

The SBA has been the traditional approach to dam engineering and dam safety. In this approach, safety is assessed by following established rules for design events and loads, structural capacity, safety coefficients, and defensive design measures. The SBA developed as a codification of the design practices of major dam owner agencies for design of new dams. Over many years, the traditional SBA has developed from recognized good practice that has been gained from basic theoretical considerations and empirical evidence. This recognized good practice, combined with experienced judgment, has generally served the objective of dam safety well, and is still a necessary component of dam safety management. Unfortunately, the SBA is not well suited for evaluating some important dam safety issues such as internal erosion, spillway gate reliability, human factors and operational issues, and others.

The RIDM approach is the process of making safety decisions by evaluating if existing risks are tolerable and present risk measures are adequate, and if not, whether alternative risk reduction measures are justified. For entities that own or regulate dams, various decisions are made regarding an individual structure or an inventory of structures, including decisions about (FEMA, 2015):

- The safety of a structure
- Necessary actions to reduce risks
- Prioritization of actions for an inventory of structures

The many benefits of the RIDM approach are well documented (ANCOLD, 2003; Bowles, 1998; Regan and Boyer, 2009). Examples of some of the purposes risk has been used to inform dam safety decisions include (modified from Environment Agency, 2009):

- To systematically identify and better understand potential failure modes.
- To identify, justify and prioritize investigations and analyses to reduce uncertainties in risk estimates for individual dams and an inventory of dams.
- To strengthen the formulation, justification and prioritization of risk reduction measures for individual dams and an inventory of dams.
- To justify decisions on reservoir operating restrictions.
- To identify ways to improve dam safety through changes in reservoir operation, monitoring and surveillance, safety management systems, staff training, emergency action planning, and business decisions related to dam safety.
- To identify opportunities to improve the effectiveness of warning and evacuation plans.
- To identify cost-effective options for more rapidly achieving reduced dam safety risks.
- To justify expenditures on dam safety improvements to owners and economic regulators.
- To identify and understand those risks that exist through normal operation (non-failure risk) of the project.
- To provide a framework for quantifying engineering judgment and communicating technical issues with dam owners in a more open and transparent manner.
- To facilitate the evaluation of dam safety risks to the public in a manner that allows comparison with other infrastructure and technological hazards.
- To provide a non-technical basis for communicating dam safety risks to the public.
- To provide a basis for development of a safety case or safety demonstration for owners and regulators.
- To assess the adequacy of insurance coverage.
- To strengthen the basis for corporate governance related to dam safety risks.
- To strengthen the exercise of the owner's duty of care, due diligence and legal defensibility with respect to dam safety incidents or dam failure.

A few benefits are worth highlighting:

- A greatly improved understanding of the safety of a dam. Risk analysis greatly improves the understanding of the dam's safety by the systematic analysis of the logic of failure mechanisms. In this sense, it is not just the numerical results, which usually have wide uncertainty, but the risk analysis process, which is the real benefit of risk assessment.

- A means of analyzing and assessing risks in areas where no traditional standards have been established. There are areas of dam safety where no clear, widely accepted SBA has been established, in particular for evaluation of the safety of existing dams, for example the reliability of spillway gates, internal erosion, and human/operational factors, to name just a few. Risk assessment provides a systematic and rationale approach for dealing with such areas.

- A proper understanding of the potential liabilities of dam ownership. The estimation and evaluation of the risks specific to a dam provides an owner with an appreciation of the liabilities that the business faces. Such an appreciation is critical to business planning.

- A basis for demonstration of due diligence. Many dam safety engineers and managers have taken the view that, if a dam meets the traditional engineering standards, then the residual risks are negligible and can therefore be tolerated. Many in the profession have come to this potentially incorrect conclusion through a long process of discussion and experience, but without actually knowing what the residual risks are. However, the residual risks are rarely zero. Risk assessment involves an examination of all hazards, an explicit estimation of residual risks, such as risks to life, and a judgment of their tolerability, and is therefore an aid to a dam owner in foreseeing risks to others and in taking timely and proportionate action to reduce risk where needed, thereby demonstrating the discharge of the duty of care.

1.1.4 Owner/Licensee Responsibilities

The dam owner and operator are in the legal position of being responsible for the safety of their dam, its operation, and the consequences of a failure should one ever occur. All dam owners should fully understand and appreciate their legal, regulatory, moral, and social obligations of owning a dam. Without a deliberate effort to understand the risks that a dam imposes on its surroundings, in both the magnitude and frequency of the hazards and magnitude of potential consequences, including impacts to life, health, and property, an owner cannot fulfill these obligations.

In addition to community interests, such as risks to life, third-party property (economic), and the environment, the owner needs to consider the financial risk relevant to business and asset risk management. This consideration should include business responsibilities to consumers and the community, credibility and political issues, and potential financial and legal liabilities arising from a dam failure. Such considerations could warrant a higher level of safety than indicated by the assessed risk to life, economic, and environmental risks.

Dam owners, in setting their own tolerable risk policies, need to have regard to FERC's RIDM guidelines, legal and political constraints within which they operate, the legitimate interests of society as a whole, and to recognize good practice.

Finally the owner has a duty and responsibility to communicate information to the community on the risks associated with dam failure, operation, and flooding.

1.1.5 Principles

The following fundamental principles apply to the overall objectives of these Risk Guidelines:

1. Life safety is paramount.
2. 'Do no harm' must underpin all actions intended to reduce dam safety risk.
3. Risk should inform the decision process. Decisions are not 'risk-based'.
4. Identify and reduce the risk to life and property posed by dams and reduce those risks to as low as reasonably practicable (ALARP).
5. The urgency of completing dam safety actions should be commensurate with the level of risk.
6. Dam safety inspections, surveillance and monitoring, emergency action plans and testing, owners dam safety plan, Part 12D Reports, training, and other routine dam safety activities are all essential parts of an effective dam safety risk management program.
7. Risk communication must be well planned, timely, and involve all parties potentially affected by the decision or a failure of the dam.

1.1.6 Terminology/Definitions

Unfortunately risk terminology is wildly inconsistent in the literature and in practice. Much of this stems from the broad use of risk terms in many industries (financial, insurance, safety, and others) both nationally and internationally. Some of the risk terms and definitions that follow conflict with other industries and other practices, including some terms used by The Office of Management and Budget (OMB) in its guidance to agencies related to risk procedures (OMB, 2007). Some of these definitions are different than the definitions included in other publications and agency-specific documents and guidance. For example, the USACE has opted to use the OMB definitions (USACE, 2014). However, for the purposes of this document, the definitions contained in the publication, *Risk Assessment in Dam Safety Management* by the International Commission on Large Dams (ICOLD) are presented (ICOLD, 2005).

Risk – A measure of the probability and severity of an adverse effect to life, health, property, or the environment.

Risk Analysis - 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. 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.

Risk Evaluation – Risk evaluation is the process of examining and judging the significance of risk. The risk evaluation stage is the point at which values (societal, regulatory, legal, and owners) and value judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, economic, and other consequences, in order to identify and evaluate a range of alternatives for managing the risks.

Risk Assessment –Risk assessment is the process of making a decision recommendation on whether existing risks are tolerable and present risk measures are adequate, and if not, whether alternative risk reduction measures are justified or will be implemented. Risk assessment incorporates the risk analysis and risk evaluation phases.

Risk Management – Risk management is the systematic application of management policies, procedures and practices to the tasks of identifying, analyzing, assessing, communicating, mitigating, and monitoring risk.

Additional risk terms and definitions are included in the glossary of terms in Appendix 1A.

1.1.7 Implementing RIDM Approaches

There are a number of possible pathways the FERC could take in implementing RIDM approaches, including using RIDM as sole method of making dam safety decisions, using RIDM as an alternative method, or using RIDM to enhance the SBA. The FERC supports using RIDM to enhance the SBA for the following reasons:

- The long term standing of the traditional SBA.

- The need to gain wider acceptance in the community of tolerable life safety criteria and ALARP.
- The need to develop improved methods for estimating the uncertainties in risks.
- The limited expertise in the dam safety profession in risk analysis and risk assessment processes.

RIDM provides an enhancement to the SBA. Satisfying the SBA does not guarantee that tolerable risk will be achieved, though that may often be the case. In general, the SBA will likely be met if tolerable risk is achieved, although there may be exceptions, which should be carefully justified. The systematic steps of potential failure mode analysis (PFMA) and ALARP evaluation in the RIDM approach will often result in dam safety issues being identified and addressed which may not have been either identified and addressed using the SBA. For these reasons, owners are encouraged to use the RIDM approach to enhance the understanding gained from the SBA. Doing so will assist the defensibility of decision making.

There was previously a view by some that risk assessment was a means to justify less costly safety upgrades of dams than those required by the SBA. It is now recognized that such a view seriously misunderstands the true aim of risk assessment, which is more informed decision making than would be possible from reliance on the SBA alone. It may be that the additional understanding that comes from the risk assessment process will reveal that a less costly solution to a dam safety problem could be justified, though a decision that way should be made with great care and having regard to all the community risk and business risk considerations. But it could as easily be the case that risk assessment shows that a more stringent safety level, and thus a more costly solution, ought to be implemented.

Additional RIDM implementation guidance is provided in Chapters 2, 3, and 4.

1.2 RISK FRAMEWORK

1.2.1 General

Using risk to inform decisions involves three distinct components (FEMA, 2015). These components, each having their own purpose and function, are:

- Risk analysis
- Risk assessment
- Risk management

Figure 1-1 shows how risk analysis, risk assessment, and risk management relate to each other. Dam safety risk management includes routine and non-routine activities and is the umbrella under which risk is used to inform decisions by owners and regulators. Risk communication, although not specifically identified in Figure 1-1, is a critical part of each component of risk management. While the main components of risk-informed decision making are risk analysis, risk assessment, and risk management, there are activities that dominate the completion of each component. For risk analysis, the key activities are dam system identification and risk estimation. For risk assessment, the key activity is risk evaluation. For risk management, the key activity for dams with high risk is risk reduction. These concepts are illustrated in Figure 1-1.

The term risk, when used in the context of dam safety, is generally comprised of three parts:

1. The likelihood of occurrence of a load (e.g., flood, earthquake, reservoir elevation, etc.),
2. The likelihood of an adverse structural response (e.g., dam failure, damaging spillway discharge, misoperation, etc.) given the load, and
3. The magnitude of the consequences resulting from that adverse event (e.g., life loss, economic damages, environmental damages, etc.) given that it occurs.

Typically, the direct consequences of dam failure are estimated. In addition, indirect consequences, those impacts that are associated with destruction of property and the displacement of people due to the failure, should also be estimated, where possible. If indirect consequences can be identified and estimated, they can be incorporated into the risk estimates. In some cases, it may not be possible to capture all of the indirect consequences. Figure 1-2 depicts the flow of recurring dam safety activities and how risk information is used to inform decisions on dam safety actions and setting priorities.

Risk estimates typically reflect the risk at a given dam at the snapshot in time when the risk analysis is performed. It is recognized that the conditions at the dam will likely change in the future and the consequences of dam failure may also change as development occurs within potential dam failure inundation boundaries. This potential future increase in consequences can be taken into account as part of a long-term consideration of risk.

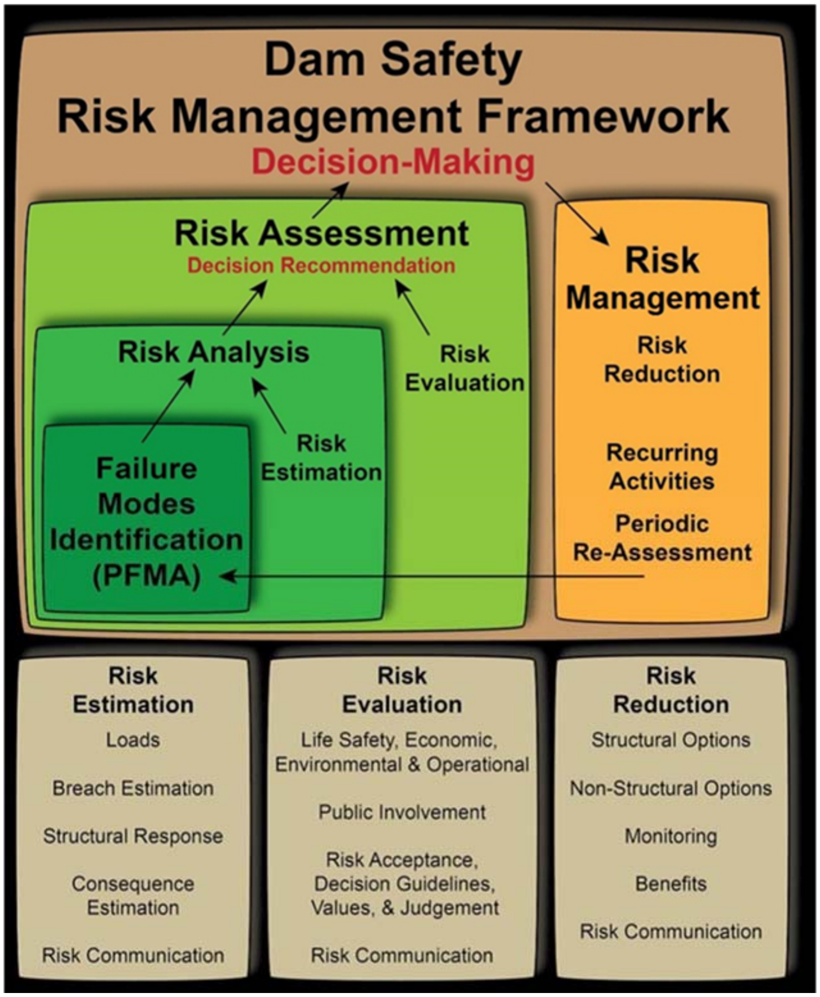

Figure 1-1. Relationship Between Risk Analysis, Risk Assessment, and Risk Management (FEMA, 2015).

1.2.2 Risk Analysis

Risk analysis is the first component of risk management (FEMA, 2015). It is the portion of the process in which the 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 specific potential failure modes that are most likely 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.

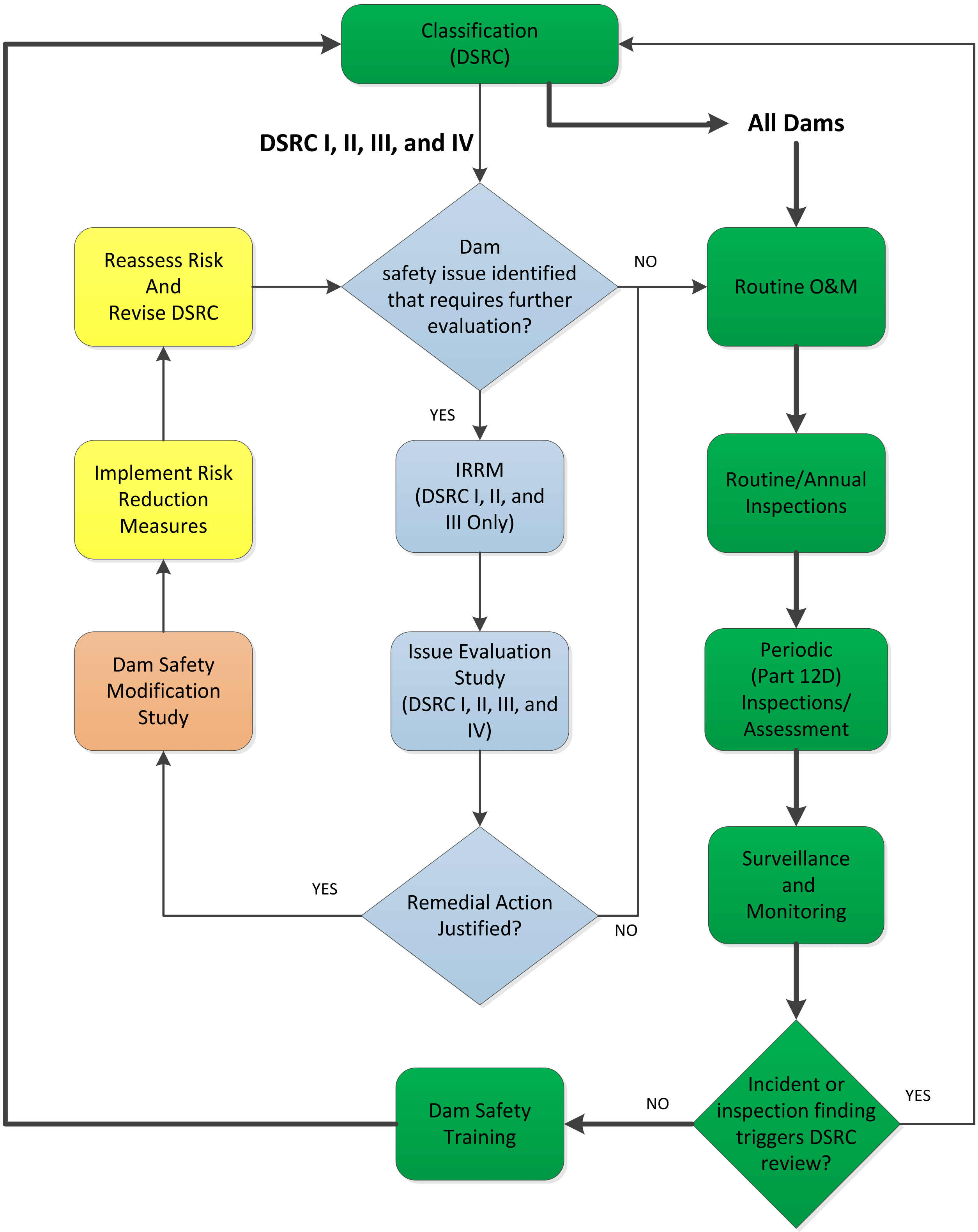

Figure 1-2. Recurring and Non-recurring Dam Safety Activities.
(Note: See Chapter 4 for terminology and definitions)

Additional information on risk analysis is presented in Chapter 2 - Risk Analysis.

1.2.3 Risk Assessment

Risk assessment is the process of examining the safety of a specific structure, making specific recommendations, and recommending decisions on a given dam or project using risk analysis, risk estimates, and other information that have the potential to influence the decision (FEMA, 2015). The risks are assessed by the dam owner and the FERC as the regulator, and if applicable, the owner's engineer, or other stakeholders. The assessment considers all factors (e.g., likelihood, consequences, cost, environmental impacts, etc.) and may also use evaluation factors established by the owner or regulator. Decisions may include additional or enhanced monitoring; additional investigations, evaluations or analyses; remedial actions; abandonment of the dam; or no additional actions.

Additional information on risk assessment is presented in Chapter 3 - Risk Assessment.

1.2.4 Risk Management

Risk management is the overarching activity when risk is used to inform dam safety decision making and builds on risk analysis and risk assessment phases. It encompasses activities related to making risk-informed decisions, prioritizing evaluations of risk, prioritizing risk reduction activities, and making program decisions associated with managing an inventory of facilities (FEMA, 2015).

From a business or management perspective, risk management (sometimes referred to as risk control) options can be grouped into the following categories, although these are 'not necessarily mutually exclusive or appropriate in all circumstances' (ICOLD, 2005):

- Avoid the risk – This is a choice, which can be made before a dam is built, or through decommissioning an existing dam.
- Reduce (prevent) the probability of occurrence – Typically through structural measures, or reservoir safety management activities such as monitoring and surveillance, and periodic inspections.
- Reduce (mitigate) the consequences – For example by non-structural approaches such as effective early warning systems or by relocating exposed populations at risk.
- Transfer the risk – For example by contractual arrangements or sale.
- Retain (accept) the risk – 'After risks have been reduced or transferred, … residual risks … are retained and … may require risk financing (e.g. insurance).'

In general, the first three options reduce the risk to which third parties are exposed. The fourth and fifth options only affect the risk that the dam owner is responsible for and not the risk to which third parties are exposed.

Risk management includes evaluating the environmental, social, cultural, ethical, political, and legal considerations during all parts of the process to assure due diligence in the management of risks. These activities include potential structural and nonstructural actions on a given dam or project, as well as activities such as routine and special inspections, instrumented monitoring and its evaluation, structural analyses, site investigations, development and testing of emergency action plans, and many other activities. All of the activities described above relate to management of risks which involves dam safety actions to reduce risk and activities to identify issues early before potential failure modes can initiate.

Additional information on risk management is presented in Chapter 4 - Risk Management.

1.2.5 Risk Communication

Risk communication is a critical component of an effective risk-informed decision process (FEMA, 2015). It is not a separate component of the process; it must be integrated into all aspects of the process. Risk communication provides many benefits, including enhancing communication with the public, internally within dam owning and regulating organizations, and emergency management agencies (EMAs) for the purposes of improving the chances that dam safety decisions will be supported within and outside of the organization, better preparing the organization and the public for taking action in the event of an emergency, and instilling confidence in the dam safety office of an organization. In this sense, risk communication is essential for all agencies, organizations, and individuals that have a stake in the dam or would be impacted by its failure.

Additional information on risk communication is presented in Chapter 4 - Risk Management.

1.3 REFERENCES

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APPENDIX 1A

GLOSSARY OF TERMS

Acceptable Risk – A risk, for the purposes of life or work, everyone who might be impacted is prepared to accept assuming no changes in risk control mechanisms. Such risk is regarded as insignificant and adequately controlled. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort. [ICOLD, 2005]

Adverse Consequences – The outcome of the failure of a dam or its appurtenances, including immediate, short and long-term, direct and indirect losses and effects. Loss may include human casualties, project benefits, monetary and economic damages, and environmental impact. [USACE, 2014]

Annual Exceedance Probability (AEP) – The estimated probability that an event of specified magnitude will be equaled or exceeded in any year. [ICOLD, 2005]

Annual Probability of Failure (APF) – The estimated annual probability of failure from an individual potential failure mode or a combination of potential failure modes associated with a specific loading or all loading or initiating event types that result in an unintentional release of the reservoir. [modified from USACE, 2014]

As-Low-As-Reasonably-Practicable (ALARP) – That principle which 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]

Average Annual Life Lost (AALL) – As used in the f-N plot, the expected value (weighted average) of potential life loss of the probability distribution of potential life loss from dam failure. [modified from USACE, 2014]

Broadly Acceptable Risk – "Risks falling into this region are generally regarded as insignificant and adequately controlled. The levels of risk characterizing this region are comparable to those that people regard as insignificant or trivial in their daily lives. They are typical of the risk from activities that are inherently not very hazardous or from hazardous activities that can be, and are, readily controlled to produce very low risks" (HSE, 2001). By the nature of the hazard that dams pose it is inappropriate to attempt to manage them as a broadly acceptable risk and therefore the concept of the broadly acceptable risk level or limit does not apply to dams. [USACE, 2014]

Catastrophe – A sudden and great disaster causing misfortune, destruction, or irreplaceable loss extensive enough to cripple activities in an area. [USACE, 2014]

Complementary Cumulative Distribution Function (CCDF) – The integral of the probability density function calculated in the direction of decreasing values of the random variable. The probability that the random variable takes on values greater than or equal to a particular value can be read from the CCDF. The F-N chart is an example of a CCDF, although the probability of N=0 is omitted. [ICOLD, 2005]

Component Risks – Estimates of risk contributed by the physical components of a dam undergoing failure mode analysis for a remediation alternative. [USACE, 2014]

Conditional Load Response Probabilities – Response probabilities (of failure) corresponding to the conditional load type and scenario under investigation. [USACE, 2014]

Conditional Probability – The probability of an outcome, given the occurrence of some event. For example, given that a flood has reached the crest of an embankment dam, the probability of the dam failing is a conditional probability. [ICOLD, 2014]

Conditional System Response Probability Estimates – System response probabilities that are conditional on the specific loading condition analyzed (over the range of loading conditions to be studied). [USACE, 2014]

Consequences – In relation to risk analysis, the outcome or result of a risk being realized. Impacts in the downstream as well as other areas, resulting from failure of the dam or its appurtenances. [ICOLD, 2005]

Cost-to-Save-a-Statistical-Life (CSSL) – CSSL is the ratio of the cost of a proposed risk reduction measure divided by the consequent estimate of 'Statistical Lives Saved'. [USACE, 2014]

Cumulative Distribution Function (CDF) – the integral of the probability density function calculated in the direction of increasing values of the random variable. Thus the probability that the random variable take on values less than or equal to a particular value can be read from the CDF. [ICOLD, 2005]

Dam Failure – Failure characterized by the sudden, rapid and uncontrolled release of impounded water or liquid-borne solids. 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]

Dam Safety Risk Classification (DSRC) – The Dam Safety Risk Classification system is intended to provide consistent and systematic guidelines for appropriate actions to address the dam safety issues and deficiencies of FERC regulated dams. FERC regulated dams are assigned a DSRC class informed by their incremental flood risk considered as a combination of probability of failure and potential life safety, economic, environmental, or other consequences.

Dam Safety Case – A logical set of arguments used to advocate a position that either additional safety-related action is justified, or that no additional safety-related action is justified at any given (current) time. It is sometimes referred to simply as "the case". [BOR, 2011]

Dam Safety Issue – Any confirmed or not yet confirmed condition at a dam that could result in intolerable life safety, economic, and environmental risks. [USACE, 2014]

Dam Safety Modification Study – The safety case that presents the investigation, documentation, and rationale for modifications for dam safety. The report presents the formulation and evaluation for a full range of risk reduction alternatives. A detailed risk analysis is required to look at incremental risk reduction alternatives that together meet the tolerable risk guidelines and cost effectiveness of reducing the risk to and below the minimum safety criteria. However, the level of detail should only be what is needed to justify the modification decision. [modified from USACE, 2014]

Deterministic – Describing a process with an outcome that is always the same for a given set of inputs. Thus the outcome is "determined" by the input. Deterministic contrasts with probabilistic, which describes a process with an outcome that can vary even though the inputs are the same. [modified from ICOLD, 2005]

Direct Economic Losses – Direct economic losses are the damage to property located downstream from the dam due to the 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. [modified from USACE, 2014]

Economic Consequences – Direct and indirect losses of the failure of a dam and other economic impacts on the regional or national economy. Part of the direct losses is the damage to property located downstream from the dam due to the failure. [modified from USACE, 2014]

Efficiency – Efficiency is the need for society to distribute and use available resources so as to achieve the greatest benefit. For dam safety investments, this means ensuring that resources and expenditure directed to safety improvements are cost-effective and that an appropriate balance between the monetary and non-monetary benefits and the monetary and non-monetary costs is achieved. [USACE, 2014]

Environmental and other Non-monetary Consequences – Direct and indirect consequences that cannot be measured in monetary terms. These stem from the impacts of the dam failure flood and loss of pool 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 and the cultural significance areas impacted. An 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. [USACE, 2014]

Equity in Risk Management – Equity, in the risk management context, is the right of individuals and society to be protected, and the right that the interests of all are treated with fairness, placing all members of society on a (more) equal footing in terms of levels of risk faced. The equity objective is addressed by requiring that all risks higher than a limit value be brought down below the limit, except in extraordinary circumstances. [USACE, 2014]

Event Tree(s) – An event tree serves as a model of the physical dam system in which each node represents an identifiable behavior of the dam or its physical components and each event should be something that happens in space or time (Hartford and Baecher, 2004). An event tree begins with a single initiating branch on the left hand side and progress toward more detailed events to the right hand side. Starting with an initiating event branch (e.g. a severe flood, an earthquake or other natural or human caused hazards), each node is divided at various nodes to generate all possible subsequent events. Each node is an origin of possible subsequent events and each branch is a possible event that is a logical consequence of the one before it, and a necessary precursor of the one that follows. As the number of events increases, the event tree structure fans outs like the branches of a tree until each event tree pathway comes to a terminal branch or a non-failure branch. Terminal branches are the system outcome or system effect of an initiating event which leads to adverse consequences or failure of the system completely or partially. Non-failure branches result from those sequences that do not lead to failure. The tree may be extended to represent the economic damages and life loss consequences associated with the terminal branches. [modified from USACE, 2014]

Existing Condition Risk Estimate – The risk estimate at a point in time. [USACE, 2014]

Expected Value – The average or central tendency of a random variable. Specifically in relation to risk analysis, the product of the probability of an event and of its consequences, aggregated over all possible values of the variable. [ICOLD, 2005]

Fault Tree Analysis – A systems engineering method for representing the logical combinations of various system states and possible causes which can contribute to a specified event (called the top event). [ICOLD, 2005]

f-N Chart – An f-N 'event' chart is composed of individual f-N pairs, where each pair typically represents one potential failure mode (or in the case of total risk, the summation of all potential failure modes). On the f-N chart, f represents the annualized failure probability over all loading ranges. N represents the estimated life loss or number of fatalities associated with an individual failure mode, or the weighted equivalent number of fatalities associated with the summation of failure modes. [BOR, 2011]

F-N Chart (plot) – This chart is a plot of the annual probability of exceedance (greater than or equal to) of potential life loss (F) vs. incremental potential loss of life (N) due to failure compared to the no failure condition. The F-N chart displays the entire estimated probability distribution of life loss for a reservoir encompassing all failure modes and all population exposure scenarios for a particular reservoir. This is a complementary cumulative distribution function. Such curves can be used to express societal risk criteria and to describe the safety levels of particular facilities. [modified from USACE, 2014 and ICOLD, 2005]

Fragility Curve **–** A function that defines the probability of failure as a function of an applied load level. A particular form of the more general 'system response'. [ICOLD, 2005]

Frequency **–** A measure of likelihood expressed as the number of occurrences of an event in a given time or in a given number of trials. See also *likelihood* and *probability*. [ICOLD, 2005]

Hazard – Hazard is anything that is a potential source of harm to a valued asset (human, animal, natural, economic, social). [USACE, 2014]

HAZUS – A database and software system sponsored by the Federal Emergency Management Agency (FEMA) for performing a range of hazard analysis, including flood loss and impacts, for a variety of levels of detail regional wherein analysis supported by national databases; and site specific wherein local data be substituted for data that would come from national databases. [USACE, 2014]

Human Factors - Human factors refer to environmental, organizational and job factors, and human and individual characteristics which influence behavior at work in a way which can affect safety. [modified from HSE, 1999b]

Incident – An event or occurrence at a dam that could potentially result in a dam safety issue, such as a spillway flood, seismic event, activation or initiation of a potential failure mode, gate operation issue, etc. that has not resulted in failure of the dam (no rapid, uncontrolled release of the reservoir), but should be documented and trigger an investigation. [modified from USACE, 2014]

Incremental Consequences - Incremental losses or damage, which dam failure might inflict on upstream areas, downstream areas, at the dam, or elsewhere, over and above any losses which might have occurred for the same natural event or conditions, had the dam not failed. [ICOLD, 2005]

Indirect Economic Impacts – Impacts 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. 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. These losses are the increment to losses above those that would have would have occurred had the dam not failed. [USACE, 2014]

Individual Risk – This term is associated with the most exposed individual who is placed in a fixed relation to a hazard, such as a dam. Individual risk is the sum of the risks from all potential failure modes associated with the hazards that affect that person. [FEMA, 2015] The increment of risk imposed on a particular individual by the existence of a hazardous facility. This increment of risk is an addition to the background risk to life, which the person would live with on a daily basis if the facility did not exist, or in the context of dam safety, if the dam did not fail. [ICOLD, 2005]

Intangible Consequences – These are consequences 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 include such things as: 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 organization and its technical staff. [ANCOLD, 2003]

Interim Risk Reduction Measure (IRRM) – Dam safety risk reduction measures that are to be formulated and undertaken for dams that are intended as interim until more permanent remediation measures are implemented. Increased monitoring and reservoir restrictions are examples of interim measures that can be taken at a project. [modified from USACE, 2014]

Intervention – An action taken during the sequence of any failure mechanism either when failure has been initiated or later to prevent or delay completion of failure progression. [USACE, 2015]

Intolerable Risk – A risk that is greater than the *tolerable risk* [ICOLD, 2005].

Inundation Map – A map showing either the actual or predicted extent of flood water within a study area for future pre-determined flood events, ongoing flood events, or past flood events. For dams, a map showing the predicted extent of inundation from controlled or uncontrolled reservoir releases for a pre-determined event scenario or scenarios. Releases may be a result of normal reservoir operation, a result of structural failure or a result of misoperation. An example of a controlled release is flood-inducing spillway discharge. An example of an uncontrolled release is overtopping and/or structural failure. An inundation map is sometimes referred to as a flood inundation map. [modified from USACE, 2014]

Issue Evaluation Studies – Issue Evaluation studies for dams are studies to better determine the nature of the dam safety issue and the degree of urgency for action. The intent of an Issue Evaluation Study is to perform a more robust and detailed level of risk assessment than used in a Level 1 or 2 risk analysis that will enable informed decisions about the need for further investigations and interim risk reduction measures implementation. The level of detail should only be what is needed to justify the decision to pursue or not to pursue a dam safety modification study.

Life Loss Consequences – The loss of human life as a result of any release from a dam. A subset of the population at risk.

Life Loss Estimates – Estimate of potential life loss from life loss estimating methodology. May be for individual failure modes, or combined for a set of potential failure modes for specified loading scenario(s). [modified from USACE, 2014]

Life Safety Tolerable Risk Guidelines – Three types of life safety tolerable risk guidelines will be used. Individual incremental life safety risk using probability of life loss and societal incremental life safety risk expressed in two different ways - probability distribution of potential life loss (F-N chart); and the f-$\bar{N}$ chart with weighted average annual life loss (AALL).

Likelihood – Used as a qualitative description of probability and frequency. [ICOLD, 2005] A description of the occurrence chance of a particular event. [USACE, 2014]

Monte Carlo Simulation - A procedure that seeks to simulate stochastic processes by random selection of values in proportion to their joint probability density function. [ICOLD, 2005]

Non-Structural Risk Reduction – Risk reduction by measures that do not require structural modification or construction related to the dam and its appurtenant works. [USACE, 2014]

Parametric Studies – Parametric studies execute one application many times with different sets of input parameters. Such studies are in-effect, systematic, carefully controlled sensitivity studies. [USACE, 2014]

Population at Risk – The population downstream of a dam that would be subject to risk from flooding in the instance of a potential dam failure; usually documented in numbers of persons at risk. [USACE, 2014]

Potential Failure Mode (PFM) – A way that dam failure can occur (i.e., the full sequence of events from initiation to failure) for a given loading condition. A condition of a potential failure mode is that it results in an uncontrolled release of the reservoir. [FEMA, 2015]

Probabilistic – A description of procedures which are based on the application of the laws of probability. Probabilistic analysis takes explicit account of the random variations in natural and other events and properties. [ICOLD, 2005]

Probability – A measure, of the likelihood, chance, or degree of belief that a particular outcome or consequence will occur. A probability provides a quantitative description of the likelihood of occurrence of a particular event. This is expressed as a value between 0 and 1. [USACE, 2014]

Probability Density Function (PDF) – A function describing the relative likelihood that a random variable will assume a particular value. [modified from ICOLD, 2005]

Probability of Failure – The probability that a component of a dam or the dam will fail, given a specified load, leading to uncontrolled release of impounded water. [modified from USACE, 2014]

Qualitative Risk Analysis – An analysis that uses verbal descriptors or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur. [modified from ICOLD, 2005]

Quantitative Risk Analysis – An analysis based on numerical values of the potential consequences and likelihood, the intention being that such values are a valid representation of the actual magnitude of the consequences and the probability of the various scenarios which are examined. [ICOLD, 2005]

Random Variable – A quantity, the magnitude of which is not exactly fixed, but rather the quantity may assume any of the number of values described by a probability density function. [ICOLD, 2005]

Redundancy – The duplication of critical components of a system with the intention of increasing reliability of the system, usually in the case of a backup or fail-safe. [USACE, 2014]

Reliability – For gate and mechanical systems reliability is defined as the likelihood of successful performance of a given project element. It may be measured on an annual basis or for some specified time period of interest or, for example, in the case of spillway gates, on a per demand basis. Mathematically, Reliability = 1 - Probability of unsatisfactory operation. [USACE, 2014]

Remediation – Implementation of long-term structural and non-structural risk reduction measures to resolve Dam Safety issues. [USACE, 2014]

Residual Risk – Risk remaining at any time. [FEMA, 2015] The remaining level of risk at any time before, during and after a program of risk mitigation measures has been taken. [ICOLD, 2005]

Resilience – The ability to avoid, minimize, withstand, and recover from the effects of adversity, whether natural or manmade, under all circumstances of use. [USACE, 2014]

Risk – A measure of the probability and severity of an adverse effect to life, health, property, or the environment. [ICOLD, 2005]

Risk Analysis - 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. 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]

Risk Assessment –The process of making a decision recommendation on whether existing risks are tolerable and present risk measures are adequate, and if not, whether alternative risk reduction measures are justified or will be implemented. Risk assessment incorporates the risk analysis and risk evaluation phases. [ICOLD, 2005]

Risk Based **-** This term implies that a comparison of a risk estimate to risk criteria is the basis for decision-making. [FEMA, 2015]

Risk Communication – Risk communication is the open, two-way exchange of information and opinion about hazards and risks leading to a better understanding of the risks and better risk management decisions. [USACE, 2014]

Risk Estimate – The end result risk evaluation generated by application of a risk engine to the potential failure mode under study. [USACE, 2014]

Risk Evaluation - The process of examining and judging the significance of risk. The risk evaluation stage is the point at which values (societal, regulatory, legal, and owners) and value judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, economic, and other consequences, in order to identify and evaluate a range of alternatives for managing the risks. [ICOLD, 2015]

Risk Exposure – The population, infrastructure, and other assets and valued resources that would be adversely impact from a dam failure. [USACE, 2014]

Risk Governance - The process of risk-informed decision making and the process by which risk-informed decisions are implemented. [FEMA, 2015]

Risk Informed – This term implies that decisions are made considering risk estimates and many other contributing factors that might include confidence in the risk estimates, risk uncertainty, deterministic analyses, and the overall dam safety case in addition to other local or regional considerations. [FEMA, 2015] Risk will play a key role in decisions related to dam safety but will not be the only information to influence the final decisions. [modified from USACE, 2014]

Risk Management – The systematic application of management policies, procedures and practices to the tasks of identifying, analyzing, assessing, communicating, mitigating, and monitoring risk. [ICOLD, 2015]

Risk Reduction Measure – Actions formulated and undertaken to reduce risk. [USACE, 2014]

Robustness – Robustness is the ability of a system to continue to operate correctly across a wide range of operational conditions, with minimal damage, alteration or loss of functionality, and to fail gracefully outside of that range. The wider the range of conditions included, the more robust the system. [USACE, 2014]

Safety – Safety is thought of as the condition of being free from danger, risk, or injury. However, safety is not something that can be absolutely achieved or guaranteed. Instead safety is the condition to which risks are managed to acceptable levels. Therefore, safety is a subjective concept based on individual perceptions of risks and their tolerability. [USACE, 2014]

Sensitivity Analysis – An analysis to determine the rate at which an output parameter varies, given unit change in one or more input parameters. Sensitivity can be visualized as the slope of the output parameter graph or surface at the relevant input parameter value or values. [ICOLD, 2005]

Societal Risk – The probability of adverse consequences from hazards that impact society as a whole and that create a social concern and potential political response because multiple fatalities occur in one event. Society is increasingly adverse to hazards as the magnitude of the consequences increases. [FEMA, 2015] The risk of widespread or large scale detriment from the realization of a defined risk, the implication being that the consequence would be on such a scale as to provoke a socio/political response, and/or that the risk (that is, the likelihood combined with the consequence) provokes public discussion and is effectively regulated by society as a whole through its political processes and regulatory mechanisms. Such large risks are typically unevenly distributed, as are their attendant benefits. Thus the construction of a dam represents a risk to those close by and a benefit to those further off, or a process may harm some future generation more than the present one. The distribution and balancing of such major costs and benefits is a classic function of Government, subject to public discussion and discussion. [HSE, 1995]

Subjective Probability – Quantified measure of belief, judgment, or confidence in the likelihood of an outcome, obtained by considering all available information honestly, fairly, and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgment regarding an evaluation, or the quality and quantity of information. It may change over time as the state of knowledge changes. [ICOLD, 2005]

System Response – How a dam responds, expressed as a conditional probability of failure, to a given scenario of applied loads and concurrent conditions. See also *fragility curve*. [ICOLD, 2005]

Tolerable Risk – A risk within a range that society can live with so as to secure the benefits provided by the dam. It is a range of risk that we do not regard as negligible or as something we might ignore, but rather as something we need to keep under review and reduce it still further if and as we can. [HSE, 1999] In addition to the tolerable risk, the ALARP considerations will be applied to determine tolerable risk. [USACE, 2014]

Tolerable Risk Guidelines – Tolerable risk guidelines are used in risk management to guide the process of examining and judging the significance of estimated risks obtained using risk assessment. The outcomes of risk assessment are inputs to the risk management decision process along with other considerations. Meeting or achieving the tolerable risk guidelines is the goal for all risk reduction measures including permanent and interim measures. [USACE, 2014]

Tolerable Risk Reference Line – The tolerable risk reference line is depicted on Figures 3-3 and 3-4 of Chapter 3 – Risk Assessment. It defines the risks separating unacceptable risk from tolerable risk within the range of tolerability conceptually depicting the ALARP principle.

Unacceptable Risk – The risk cannot be justified except under extraordinary circumstances. [modified from USACE, 2014]

Unacceptable Risk Region – The region within the risk range (shown on Figures 3-3 and 3-4 in Chapter 3 – Risk Assessment) that is above the zone referred to as the 'Range of Tolerability'. In the 'Unacceptable Region' the risk is considered unacceptable and cannot be justified except in extraordinary circumstance. [HSE, 2001]

Uncertainty – The result of imperfect knowledge about the present or future state of a system, event, situation, or population under consideration. [FEMA, 2015]

Willingness-to-Pay-to-Prevent-a-Statistical-Fatality – This is defined as the economic principle that attempts to place a value on a potential life lost by determining the willingness of society to pay to prevent a statistical fatality. Such values are determined from studies of court cases involving involuntary death, from Federal and other agency studies of establishing regulatory standards for public safety. [USACE, 2014]