

Federal Guidelines for Dam Safety Risk Management

I. Background

Agencies, owners, and regulators have been using risk to inform decisions within various industries across the world for quite some time. In particular, the United States, the United Kingdom, the Netherlands, and Australia have integrated risk into safety decisions in various ways since the 1950's. Those entities that analyze, evaluate, and manage risks have found that risk provides a rigorous, systematic, and thorough process that improves the quality of and support for safety decisions. Several entities in the dam safety industry have been using risk to inform decision since the late 1980's. Notably, the Australian Committee on Large Dams, BC Hydro, and the Bureau of Reclamation adopted risk management strategies to assess and manage risks for their dams. For entities that own or regulate dams, various decisions are made with respect to an individual structure or for a portfolio of structures:

- Decisions regarding the safety of a structure
- Decisions regarding actions to reduce risks
- Decisions related to prioritizing actions within a portfolio of structures

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

- Risk Analysis
- Risk Assessment
- Risk Management

Figure 1 shows how risk management, risk assessment, and risk analysis 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, is a critical part of each component of risk management.

The term *risk* when used in the context of dam safety is comprised of three parts – (1) the likelihood of occurrence of a load (e.g. flood, earthquake, etc.), (2) the likelihood of an adverse structural response (e.g. dam failure, damaging spillway discharge, etc.), and (3) the magnitude of the consequences resulting from that adverse event (life loss, economic damages, environmental damages, etc.). Figure 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.

A. Risk Analysis

Risk analysis is the first component of risk management. It is the portion of the process in which the potential failure modes, structural performance, and adverse consequences such as large operational discharges are identified and for which a quantitative or qualitative estimate of the likelihood of occurrence and magnitude of consequence of these potential events are made. A critical first step of a risk analysis is the identification of the specific

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potential failure modes that are most likely at a given dam. The frequency of occurrence of the loadings (reservoir load levels, floods, earthquakes, ice loading, etc.) that could initiate potential failure that might cause adverse consequences are estimated and considered as part of a risk analysis.

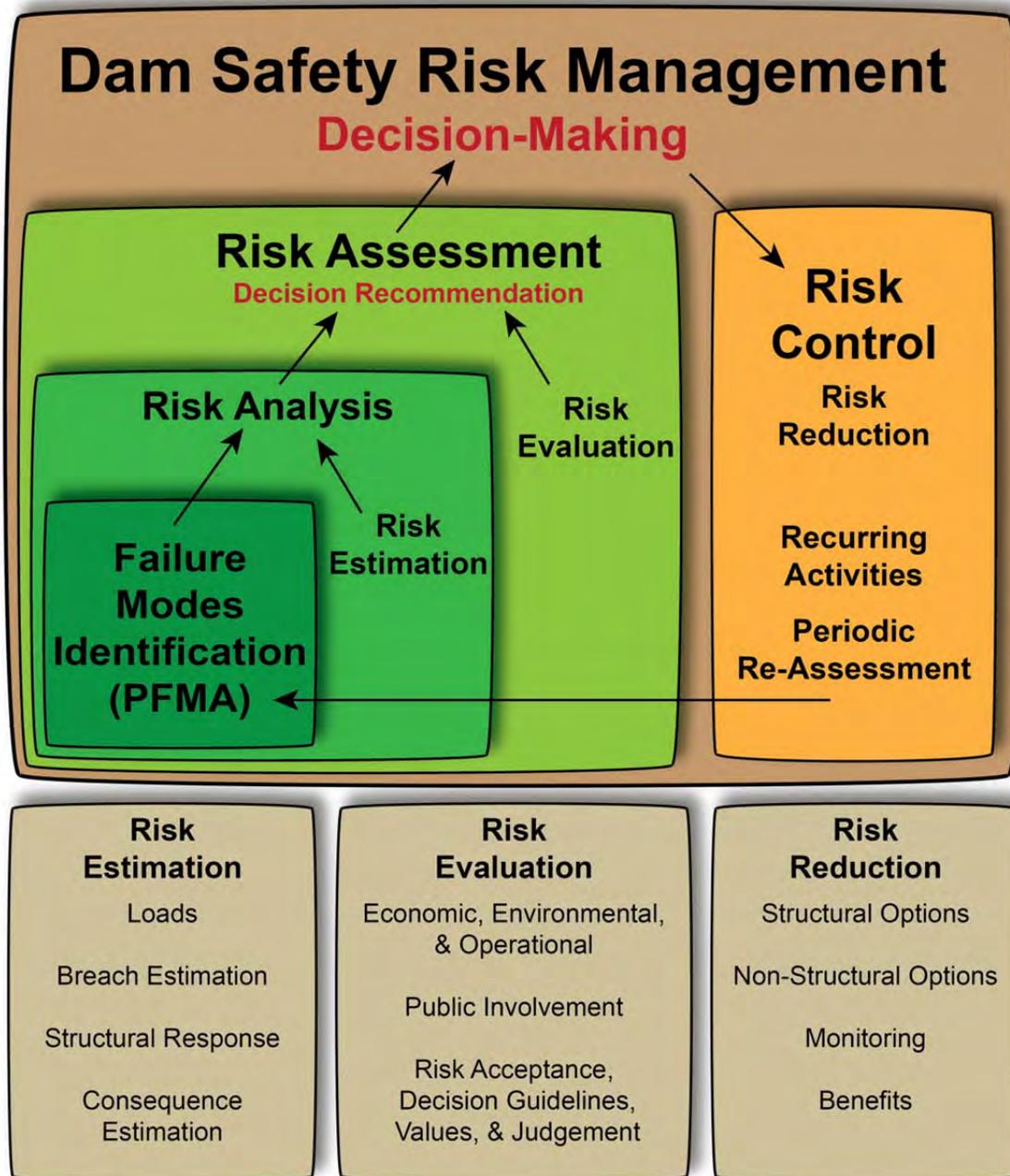


Figure 1 - Relationship between Risk Analysis, Risk Assessment and Risk Management

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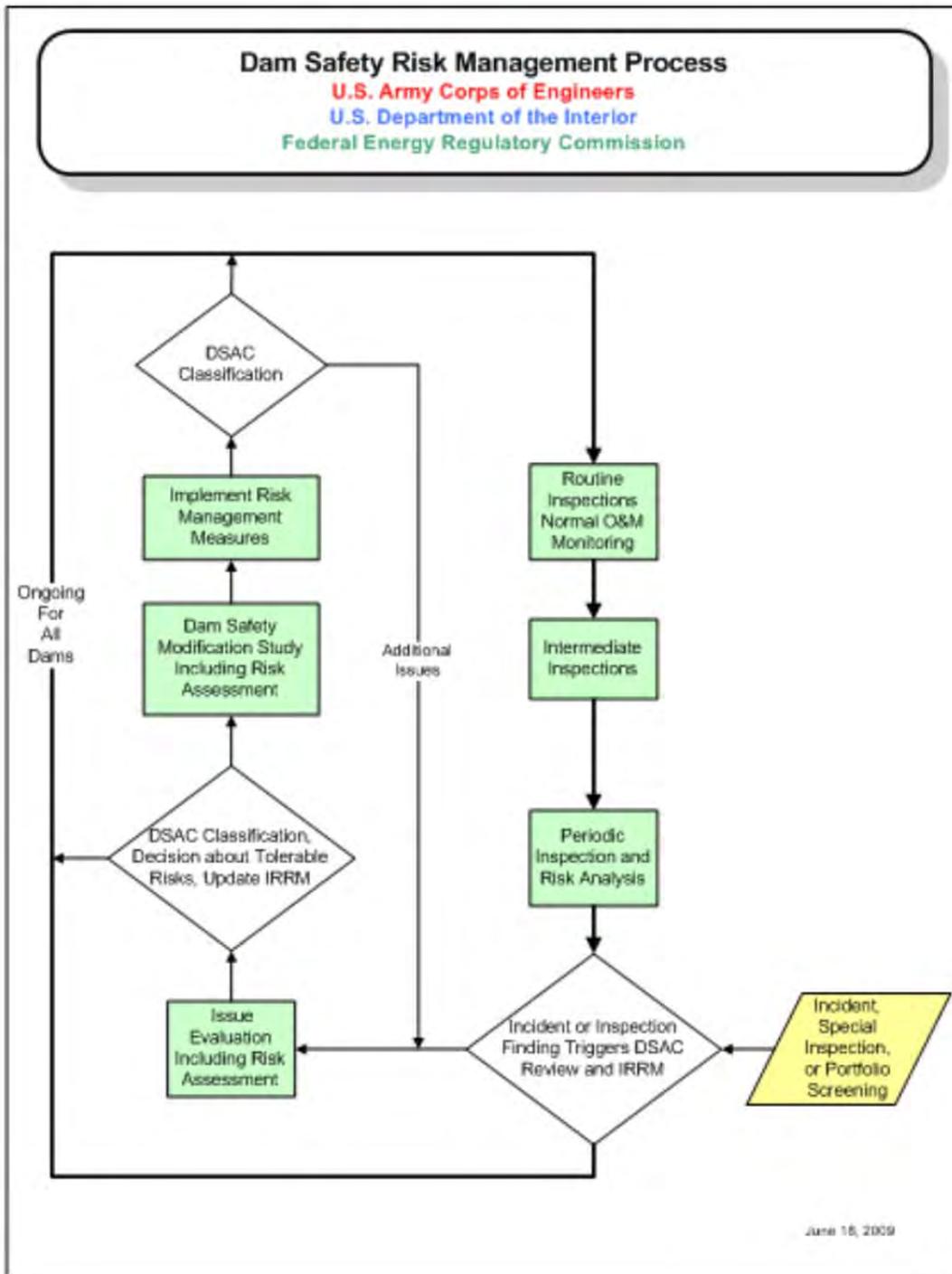


Figure 2 – Recurring dam safety activities

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B. *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. The risks are assessed by the dam owner and – if applicable – the regulator, owner’s engineer, or other stakeholders. The assessment considers all factors (likelihood, consequences, cost, environmental impacts, etc.) and may also use evaluation criteria established by the owner or regulator. Decisions may include additional or enhanced monitoring, additional investigations and/or studies/evaluations/analyses, remedial actions or abandonment of the dam, or no additional actions.

C. *Risk Management*

Risk management encompasses activities related to making risk-informed decisions, prioritizing evaluations of risk, prioritizing risk reduction activities, and making program decisions associated with managing a portfolio of facilities. Risk management includes evaluating the environmental, social, cultural, ethical, political, and legal considerations during all parts of the process. These include potential structural and non-structural actions on a given dam or project, but also include such activities 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.

D. *Risk Communication*

Risk communication is a critical component of an effective risk informed decision process. It is not identified as a separate component of the process but rather it is something that must be integrated into all aspects of the process. Risk communication is essential within an owner/regulator organization but also with other individuals/organizations who have a stake in the dam or would be impacted by its failure.

II. Objectives of the Guideline

Federal Agencies seek to ensure the structural integrity and operational safety of the dams in their charge and in so doing wisely allocate the use of monetary and human resources.

Federal agencies consider in the exercise of their Dam Safety responsibilities, that:

- There are certain principles that should be held in common for consistency and correctness;
- There should be a common understanding of risk management processes;
- There are commonly recognized standards for safety and tolerable risk, and;
- There are technical tools and approaches related to risk analysis that can be mutually shared and jointly developed.

Risk Analysis and Risk Assessment provide fundamental input to risk-informed decisions and to the extent that is reasonable and practicable, the tools, procedures, and guidelines should be consistent among the agencies.

This guideline will provide the means by which Federal agencies will use the general principles of risk management and using risk to inform decisions. The agencies will work to develop and maintain consistent application of Risk Analysis, Risk Assessment, Risk Management and Risk Communication using equivalent procedures and tools.

The guidance offered and the specific procedures identified in this guideline are not mandated and the agency may vary in the application of these guidelines as necessary to accomplish their respective missions. Definitions of selected terms related to risk informed decision process are provided in Appendix A for consistency in the use and implementation of this guideline.

The following principles apply to the overall objectives of this guideline:

1. Life safety is paramount.
2. Risk should inform decision process and improve the state of safety related to dams.
3. Identify and reduce the risk to life and property posed by dams and reduce those risks to as low as reasonably practicable.
4. Each agency has a unique authority, mission, and management practice. Their use of risk to inform decisions may vary.
5. .
6. The urgency of completing dam safety actions should be commensurate with the level of risk.

III. Risk Analysis

A. *Risk Analysis / Risk Estimation*

Risk analysis is typically a quantitative process (i.e. the outputs and inputs to a risk assessment are numeric). However, risk may also be expressed qualitatively. Risk analyses can provide valuable input to decisions made at various stages of a project or for varying purposes. They can include decisions made for a single dam or within a portfolio of dams. Thus, several types of risk analyses can be used as described below. The first step common to all types of risk analyses is the identification of the site-specific potential failure modes. Risks are typically quantitatively evaluated by failure mode. The failure modes are then rolled up within a decision framework at a particular structure. For a given dam or project, all the relevant types of loadings that may be experienced should be considered when identifying potential failure modes.

Methods to calculate and estimate risks are constantly evolving. This document does not try to describe in detail how to analyze risks, it only describes the general practices used by

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those who analyze risks. The current state-of-the-practice for analyzing risks is the Best Practices in Dam Safety Risk Analysis, which is a document and accompanying training course developed by the Bureau of Reclamation and the Corps of Engineers.

B. *Types of Risk Analysis*

There are various types of risk analysis. The level of information and the uncertainty reflected in the risk estimates will vary. Generally, more detailed risk analyses (those associated with Issue Evaluations and Risk Reduction) have more detailed analyses available and studies have been performed to try to reduce the amount of uncertainty. More detailed risk analyses will generally be led by an experienced facilitator and be done by a qualified multi-disciplinary team.

Potential Failure Modes Analysis

A potential failure modes analysis is a critical first step in conducting a risk analysis. It requires a detailed records review and a review of dam performance (instrumentation, visual, operational). Some information is also needed on flood and earthquake frequencies in order to consider hydrologic and seismic potential failure modes. The perspective of local office personnel, including dam operators, inspectors, and dam tenders is invaluable. The goal of a potential failure modes analysis is to identify the site-specific credible potential failure modes for a given dam and provide complete descriptions of the potential failure modes, including the initiating event, the progression steps leading to an uncontrolled release of the reservoir, a general description of the magnitude of the breach including identification and recording of the factors that make the potential failure more likely and those that make it less likely. Similarly, factors that make the consequences more or less severe are identified and documented.

Screening Level Risk Analysis

A screening level risk analysis is typically performed for a portfolio of dams. The goal is to identify potential failure modes and develop relative risk estimates for each dam such that the relative risk among the dams can be evaluated and priorities for further study or remediation can be established. Information on loadings, consequences and analyses that relate to potential failure modes may be very basic and limited and typically consist of what was already available or prepared just in advance of the screening effort. Screening level risk analyses have typically had very mixed results in terms of identifying key dam safety issues. A screening level risk analysis can be a valuable tool for identifying uncertainties related to potential failure modes and significant dam safety issues. They can be used to prioritize additional studies and initiate modification studies at dams. Screening level risk analyses can either be made quantitatively or qualitatively.

Periodic Risk Analysis

A periodic inspection of all dams is required under the Federal Guidelines for Dam Safety¹. A comprehensive, periodic dam safety review that documents the condition of the dam at a point in time should incorporate a risk analysis to enhance the value of the effort. Additional analyses and studies are typically not performed specifically for a periodic risk analysis as the analysis relies on existing information. The risk analysis for a periodic dam safety review can be performed by an individual, but there are distinct advantages to

¹ Federal Guidelines for Dam Safety. Federal Emergency Management Agency. September 2005.

engaging a small team. A periodic risk analysis focuses on all potential failure modes that are considered credible at the dam. Periodic dam safety reviews of dams are performed on a recurring cycle, with the interval between assessments determined by the agency.

Issue Evaluation Risk Analysis

Issue evaluation risk analyses are typically facilitator-led team risk analyses and are focused on a specific potential failure mode (or perhaps more than one potential failure mode) that may require additional engineering analyses, studies, or investigations to support a quantitative risk analysis. These supporting activities are completed to reduce uncertainty and increase confidence in the resulting risk estimates. Typically field explorations, material testing programs, detailed studies and analyses or a combination of these will be performed to provide information for the risk analysis. Analyses and studies may focus on loadings, structural response, consequences, or a combination of these. Issue evaluation risk analyses are usually conducted with an experienced risk analysis facilitator and a team with experience and backgrounds that match with the potential failure mode or modes being evaluated.

Risk Reduction Analysis

A risk reduction analysis is used to estimate the anticipated risk for critical potential failure modes after potential dam modifications or non-structural measures are implemented. Risk Reduction Analyses of the proposed alternative remediation measures are necessary to verify that planned remediation measures will achieve the desired risk reduction result. They are used when evaluating risk reduction alternatives and should be one of the factors considered when selecting a preferred alternative. They typically involve reviewing risk estimates from an existing risk analysis, deciding which events will be impacted by the changes and re-estimating the likelihood of those events.

C. *Quantitative versus Qualitative Risk Analyses*

Each type of risk analysis can be accomplished using either a quantitative or qualitative approach. In both of these approaches 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 is documented. The magnitude of consequences related to a potential failure is also characterized (quantified), discussed, and documented.

D. *Risk Analysis Results*

Risk analysis results are typically portrayed with plots that graphically portray the risk estimates (likelihood of failure vs. economic loss and potential life loss) with an accompanying table that provides the input data used to generate the graphs. Two types of graphs are typically used. The first plots individual failure modes that portrays the potential for life loss as the estimated number of lives that would be lost (N) on the x axis and the annualized probability of the failure (f) associated with the life loss on the y axis and is referred to as an f-N plot. An f-N plot depicts both societal and individual risk. In addition to risk estimates for individual potential failure modes, the total risk for the facility is plotted. The second plots the cumulative risk posed by all failure modes and the associated potential life loss and is commonly referred to as an F-N plot. An F-N plot depicts societal risk. Both f-N and F-N plots require quantitative risk estimates. Figures 3 thru 6 are examples of f-N and F-N plots. For qualitative risk estimates, the results can be plotted using a matrix (see **Error! Reference source not found.**). Figures 8 and 9 provide

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examples of an f-n and F-n plot with data added. Figure 9 depicts cumulative risk as well as risk for individual potential failure modes.

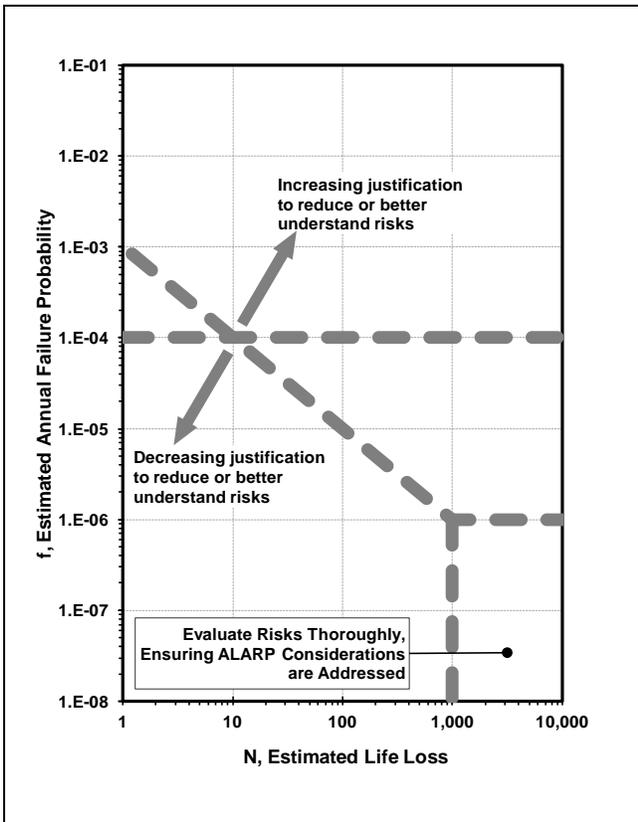


Figure 32 - Bureau of Reclamation f-N Plot

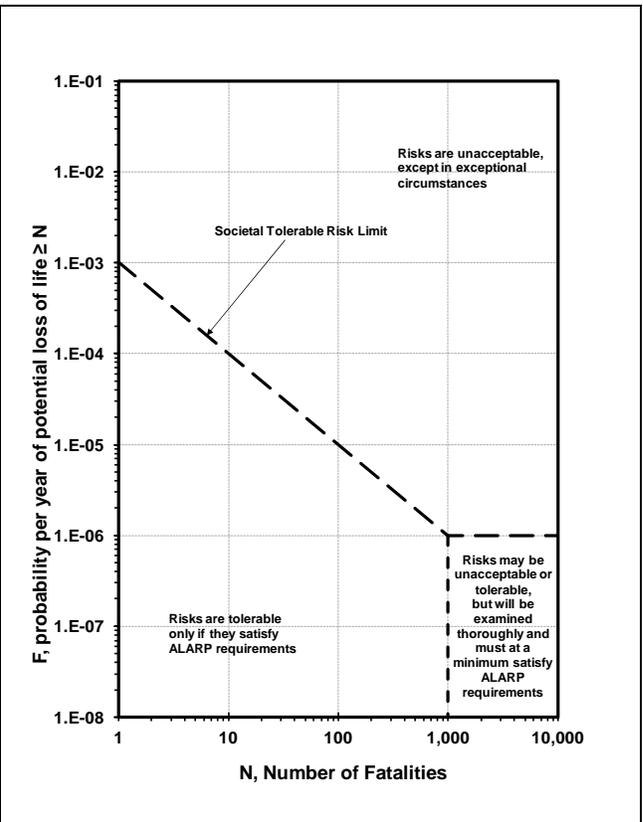


Figure 43 - U.S. Army Corps of Engineers Societal Risk Plot

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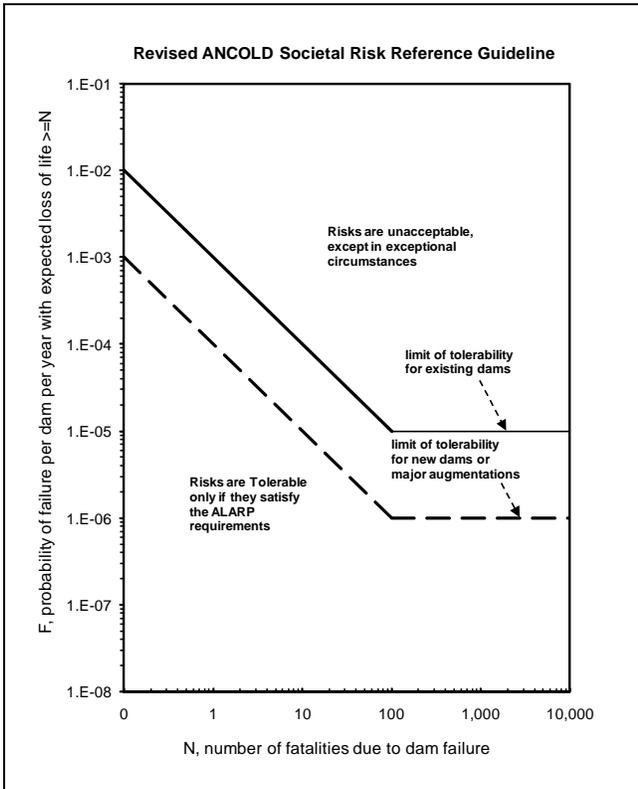


Figure 54 - Australian National Committee on Large Dams Societal Risk Plot

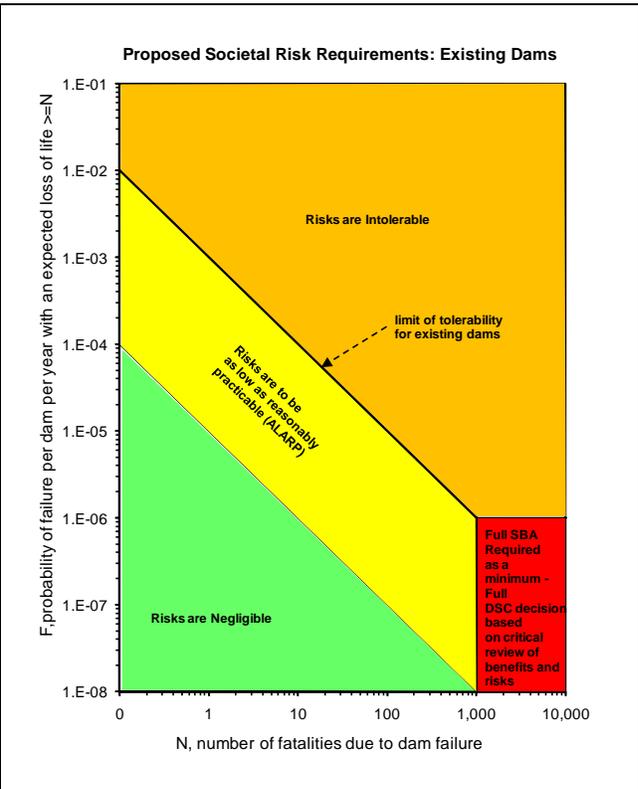


Figure 6 - New South Wales Dam Safety Committee Societal Risk Plot

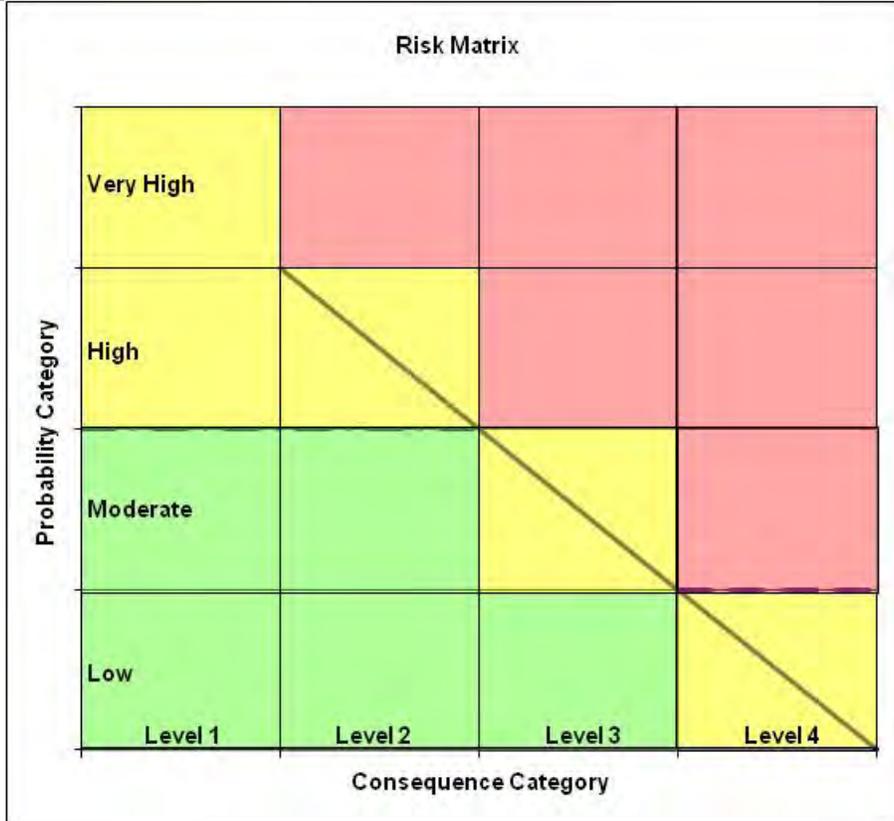


Figure 75 - Qualitative Risk Matrix

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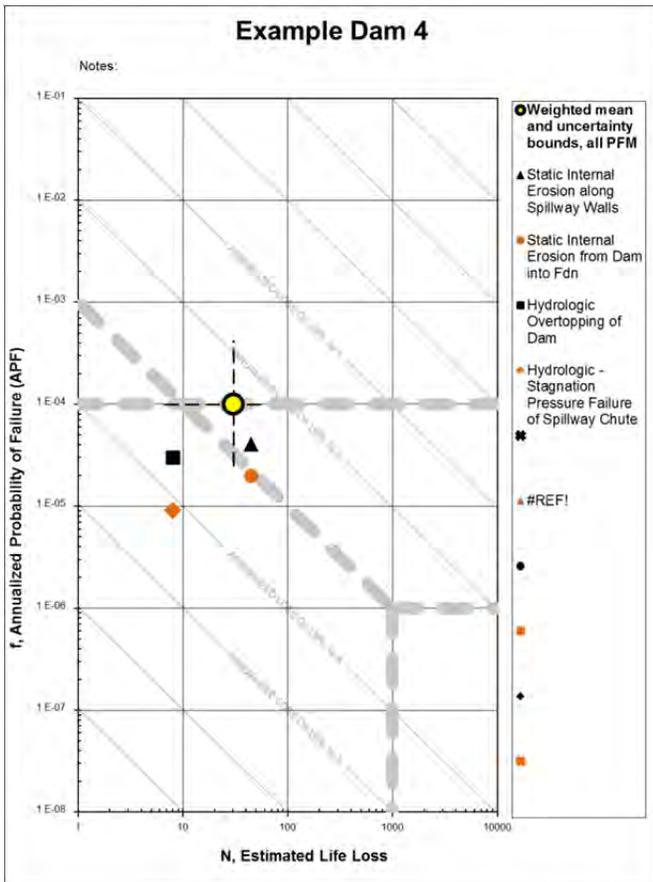


Figure 8 – An f-N plot showing individual potential failure mode and total risk.

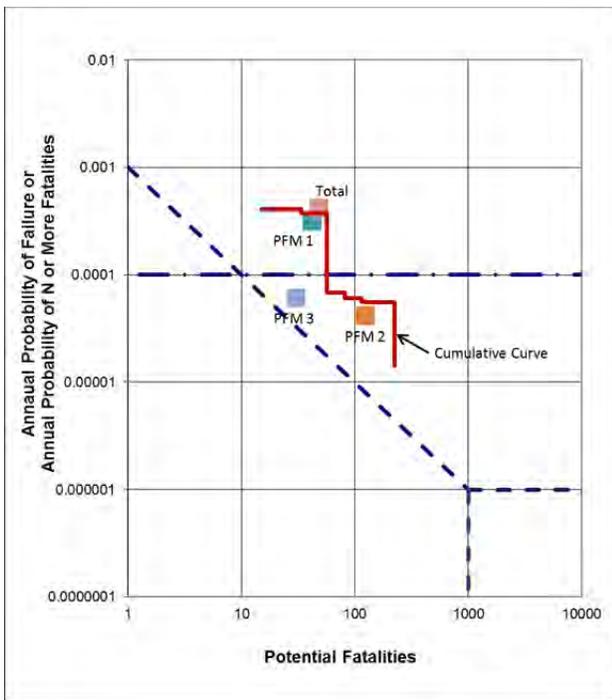


Figure 9 – An F-N plot showing cumulative risk with individual potential failure mode risks added.

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1. **Preparing the Dam Safety Case**

Numerical risk estimates are based on judgments, are typically subjective, and include varying degrees of uncertainty. These estimates should not be the sole basis to inform decisions. Understanding the basis of the risk estimates is as important as the risk numbers themselves. The dam safety case is a logical and balanced 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. The arguments string together key evidence regarding the three basic risk components, (load probability, response likelihood, and consequences) so as to support decisions related to a dam's existing condition or ability to withstand future loading. The Dam Safety Case should be initially developed in the risk analysis phase and completed as part of the risk assessment for a given dam.

IV. **Risk Assessment**

The following principles apply to risk analysis:

7. The basis for a coherent risk analysis should be a thorough examination and description of potential failure modes analysis.
8. It should be recognized that each dam is unique in terms of purpose, geologic and demographic setting, design, structure, operations and consequences
9. A well constructed dam safety case should include a discussion that supports and supplements the numerical risk estimates.

A. ***Risk Assessment / Risk Evaluation Process***

Risk Assessment is the process of considering the quantitative or qualitative estimate of risk of the existing dam or project along with all other factors related to a safety decision such as the dam safety case, social / economic impacts, environmental impacts, constructability and potential to do harm. The risk assessment is made to determine a recommended course of action (which may involve considering a range of options) with regard to mitigating or accepting the risks related to a specific dam or project or with regard to a specific dam safety issue or operational concern on that project.

The assessment and the decision is typically made by a technically qualified and experienced team (rather than a single individual) that can discern the relative criticality, the measure of concern and the type and degree of remedial action needed to address the issue. The most obvious and direct factors that enter into the assessment are the results of a risk

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analysis. These results may come in the form of quantitative / numeric results or in the form of qualitative statements that indicate the measure of concern relative to public safety.

Quantitative results provide three measures related to risk. They are:

- Likelihood of occurrence of a failure or adverse consequence in terms of annual probability.
- Estimated population at risk and/or life loss given failure or adverse consequence presented as the total estimated loss for a given annual probability of failure (often plotted or graphed) or the product of those two values which is called the “annualized life loss”.
- The economic damages (downstream damages, cost to rebuild facilities, loss of operational revenue, regional social /economic damages, environmental damages, etc.). Again these can be given or plotted as the lost economic value versus the annual probability of occurrence or as an annualized cost.

However, there are many other factors that should be included in Dam Safety Case and are considered in the decision recommendation, these include:

- The risk analysis input for the dam safety case.
- environmental considerations
- public perception and public input
- regional social and economic considerations
- ease, difficulty and practicality of remediation
- potential to do harm as the result of carrying out remediation
- uncertainty in the results and in the remediation success

This document focuses on a risk informed approach to make decisions. This method has the advantage of providing a more consistent basis for decision making. And since it is risk-informed rather than risk-based, it allows for other important factors to be considered in decision making, beyond a sole reliance on numerical risk estimates.

B. *The Dam Safety Case*

The risk estimates and the recommended actions need to be coherent. Since uncertainty is inherent in each assertion, the arguments should also address whether confidence is high enough for the assertions to stand on the basis of existing evidence.

The dam safety case and the identification of risk management options are recognized as essential elements to ensure public protection. They represent the understanding of existing conditions and predicted future behavior stated as objectively as possible

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C. **Approach to Making Risk Informed Decisions**

The concept and practice of the use of risk to inform dam safety risk assessment decisions evolved primarily from the recognition of and the desire to address the great deviation in the magnitude of potential life loss and to a lesser degree great variation in economic impact of potential failure of dams classified as high hazard. When Dam Safety became a strong force in the late 70's, decisions were primarily based on the standard hazard classification of the dam (high, significant or low). Thus, a dam which had an estimated potential life loss of more than 1 person given dam failure was classified and treated the same as one which may have a potential life loss of several thousand. This lack of discrimination between the levels of consequences among high hazard dams led to proposals of criteria that would take the magnitude of loss into consideration. Among others, ANCOLD², British Columbia Hydro, the Netherlands, and the Bureau of Reclamation³ proposed or developed evaluation criteria or guidelines.

The above discussion presumes that a quantitative risk analysis is to be carried out. However, it may be noted that evaluation criteria could also be readily established, converted, or mapped for a qualitative risk analysis.

D. **Tolerable Risk**

Inherent in the use of risk analysis and risk informed criteria or guidelines and specifically in risk assessment is the recognition and understanding of *tolerable risk*.

When risk assessment teams make decisions such as: (1) remediation for a project or dam will not be required – but that monitoring of the concern will continue, or (2) that a significant non-structural action will not be required or (3) that an alternative that addresses the major portion of the concern but does not deal with all aspects will be the course of action, then the risk remaining, related to that issue, is considered a *tolerable risk*. It can also be thought of considered or called the *residual risk*. It is the risk that remains after prudent actions to address the risk have been taken or the remote risk associated with a condition that was judged to not be a credible dam safety issue.

Another way of describing or thinking about tolerable risk, is that after hearing all the facts and information related to an issue or issues on a dam or project, an organization decides that further action is not reasonably practicable. There are many factors other than the numerical estimate of risk that can contribute to the decision that no further action is justified, including:

- The cost to reduce risks further;
- The level of certainty or uncertainty on various aspects of the problem;
- A precedent of comparable decisions on other projects;
- The possibility that the concern is not reasonable to address in a practical manner;

² Guidelines on Risk Assessment, Australian National Committee on Large Dams, October 2003.

³ Guidelines for Achieving Public Protection in Dam Safety Decisionmaking. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado. June 15, 2003.

- The chance of success of an action;
- Time to perform the remediation, and;
- Other considerations.

It should also be recognized that regardless of what actions are taken or not taken there will always be a certain residual risk. Therefore rather than ignoring or pretending that the risk is zero, it is appropriate that tolerable risk levels for various aspects of the dam be discussed and identified .

The following principles apply to risk assessment:

10. Remedial actions should do no harm.
11. Decisions should be risk-informed and not risk-based.
12. Interim risk reduction measures should be considered and implemented where needed.

V. Risk Management

Risk management encompasses activities related to making risk-informed decisions, prioritizing evaluations of risk, prioritizing risk reduction activities, and making program decisions associated with managing a portfolio of facilities. Risk Management processes vary with respect to an organization's dam safety governance. Risk Management is greatly facilitated and enhanced by having the base of knowledge supplied by the risk analyses and risk assessment inputs for the dams as described above. Such knowledge allows a logical and consistent basis for substantiating and prioritizing risk reduction activities and/or making program decisions associated with managing a portfolio of facilities. Risk management, by virtue of its use of the findings from a risk assessment / risk evaluation process, includes considering the environmental, social, cultural, ethical, political, and legal factors. Risk management should be regarded as an ongoing and iterative process that needs to adapt to new information.

The primary goal of risk management is to implement actions to either: accept, further monitor or evaluate, control or reduce risk, while considering the cost and benefits of any actions taken. When reducing risk either at a single dam or within a portfolio of dams, actions should be taken as quickly and as efficiently as possible, recognizing that there will likely be limits on available funding. Consideration should be given to the amount of risk reduction achieved for the cost of achieving risk reduction. Generally the priorities will be to fix the dams with the highest perceived risk first (assuming there is confidence in the risk estimates), but if the cost of reducing risk at the highest risk dam is disproportional to the risk reduction achieved, it may be appropriate to consider risk reduction activities at other dams first.

The agencies recognize that the methods used to calculate risks do not provide precise numerical results. Therefore, relying solely on the numeric estimates in comparison to definite established

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criteria (risk-based evaluation criteria) would not be appropriate. Decisions are generally more complex than can be portrayed using only the numerical results of a risk analysis. The strength of the dam safety case should also be considered in the risk management phase.

In order to effectively prioritize dam safety actions, information on the cost of the actions, the risk reduction potential, and the duration of the actions is needed. This type of information is needed to evaluate the efficiency of risk reduction actions and can be used to fine-tune dam safety actions. A record of the baseline risks, the dam safety case and rating and updates that resulted from risk reduction activities should be maintained for each dam in an agency's inventory.

For federal dam owner's with large dam inventories or for private dam owner's with large dam inventories, prioritizing dam safety actions will be important, since funding will limit how quickly actions can be completed. If an owner is dealing with a large dam inventory, a risk categorization scheme may be helpful in making an initial cut at prioritizing dam safety actions. A method of categorizing dams by risk is outlined in Table 1. This will provide an initial sorting of dam safety actions, but further refinements within the categories will be needed. The following factors should be considered for refined prioritization (each of these factors will contribute to increasing the priority of actions at a given dam):

- Both the failure probability and the annualized life loss exceed the threshold guideline values.
- The failure probability or the annualized life loss is driven by a single potential failure mode.
- The failure probability or the annualized life loss is driven by a potential failure mode manifesting itself during normal operating conditions.
- The range of risk estimates is tightly clustered and the mean and median are similar (for detailed uncertainty analyses only) and/or sensitivity studies instill confidence.
- Risk reduction or confirmation is relatively easy and inexpensive.

The above factors can also be considered if a dam appears borderline between two categories. If a dam owner has a small inventory of dams, the above factors alone can be used as the basis for establishing priorities. The initial effort to place the actions in one of the five risk categories would have limited value for small dam inventories.

Prioritization of dam safety actions can be done on a facility basis (where total risk is the focal point and the goal is to reduce total risk to tolerable levels) or on an individual potential failure mode basis (where single potential failure modes are addressed).

URGENCY OF ACTION	CHARACTERISTICS AND CONSIDERATIONS	POTENTIAL ACTIONS
I - VERY HIGH URGENCY	<p>CRITICALLY NEAR FAILURE: There is direct evidence that failure is in progress and the dam is almost certain to fail during normal operations if action is not taken quickly.</p> <p>OR EXTREMELY HIGH RISK: Combination of life or economic consequences and likelihood of failure is very high with high confidence.</p>	<ul style="list-style-type: none"> • Take immediate action to avoid failure. Communicate findings to potentially affected parties. • Implement interim risk reduction measures. • Ensure the emergency action plan is current and functionally tested. • Conduct heightened monitoring and evaluation. Expedite investigations and actions to support long-term risk reduction. • Initiate intensive management and situation reports.
II - HIGH URGENCY	<p>RISK IS HIGH WITH HIGH CONFIDENCE OR VERY HIGH WITH LOW TO MODERATE CONFIDENCE: The likelihood of failure from one of these occurrences, prior to taking some action, is too high to delay action.</p>	<ul style="list-style-type: none"> • Implement interim risk reduction measures. • Ensure the emergency action plan is current and functionally tested. • Give high priority to heightened monitoring and evaluation. Expedite investigations and actions to support long-term risk reduction. • Expedite confirmation of classification.
III - MODERATE URGENCY	<p>MODERATE TO HIGH RISK: Confidence in the risk estimates is at least moderate.</p>	<ul style="list-style-type: none"> • Implement interim risk reduction measures. • Ensure the emergency action plan is current and functionally tested. • Conduct heightened monitoring and evaluation. Prioritize investigations and actions to support long-term risk reduction. • Prioritize confirmation of classification as appropriate.
IV – LOW TO MODERATE URGENCY	<p>LOW TO MODERATE RISK: The risks are low to moderate and confidence in the risk estimates is low with the potential for the classification to move higher, with further study.</p>	<ul style="list-style-type: none"> • Ensure routine risk management measures are in place. • Determine whether action can wait until after the next periodic review • Before the next periodic review, take appropriate interim measures and schedule other actions as appropriate. • Give normal priority to investigations to validate classification, but do not plan for risk reduction measures at this time.
V – NO URGENCY	<p>LOW RISK: The risks are low and are unlikely to change with additional investigations or studies.</p>	<ul style="list-style-type: none"> • Continue routine dam safety risk management activities and normal operations and maintenance.

Table 1 – Proposed Joint Federal Risk Categories Table

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The following principles apply to risk management:

13. The objective of an organization should be to reduce dam safety risk as effectively and as efficiently as possible.
14. Each organization should have a transparent process for establishing priorities and the urgency of completing dam safety actions.
15. Incorporate flexibility in prioritizing work within a portfolio, allowing for adjustments in planned work as new high priority issues are identified.
16. Use a dedicated, established group to review and prioritize proposed dam safety actions within a portfolio or when establishing urgency for action at a specific dam.
17. Independent review is critical to the credibility of this process.
18. The urgency of completing dam safety actions should be commensurate with risk

VI. Section 4 – Risk Communication / Public Awareness

Communication is important in all aspects of dam safety - within an organization, with the public and with the specific owners or stakeholders of a project. However, communication about the work associated with risk is particularly important because of the fears, sentiments, perceptions, and emotions surrounding the word *risk* and the use of *risk analysis* in engineering.

Thus, it is important to understand and have a good plan for communication risk, including:

- What information is available at a given dam related to potential failure modes and how the information is considered in a risk analysis;
- How risk will be considered by an organization;
- What the results of the risk analyses are, and;
- What decisions were reached and what risk remains.

This communication can help create an awareness of potential dam safety issues and help all parties gain a greater understanding. Creating an understanding of risk and dam safety issues is important within an organization, among the public, and among owners and stakeholders who have varying degrees of connections to the dam and the associated potential impacts. Those groups have a variety of backgrounds, experience, and sophistication. Communication plans and strategies should be developed for the following:

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- Internal to a dam safety organization;
- Owners and stakeholders;
- Dam site and project personnel;
- Local organizations;
- Technical organizations or consultants;
- Decision-makers, and;
- The public.

A. ***Internal Communication within a dam safety organization***

There are at least four levels at which communication garnered from risk studies and resulting decisions need to take place within an organization. These include:

- Communication from and to employees at the dam or project site,
- Communication at the local level of the organization, where the responsibility for managing the operation, maintenance and the routine visual surveillance and instrumental monitoring for the suite of dams associated with one or more projects typically resides;
- Communication at the technical level where traditional engineering and geologic studies and investigations are performed, where risk analyses and risk assessments are carried out and where independent staff check and review studies, analyses and risk analysis results; and
- Communication at the decision making level, where funding is secured and decisions are made regarding dam safety actions and risk management decisions on program priorities are made.

1. **Dam Site and Project Site Personnel**

The dam tenders, inspectors, staff performing visual inspections and taking readings of seepage and instruments, and plant operators responsible for gate operations provide a valuable source of ground truth relative to risk analyses and need to be communicated with in that regard. Dam operators often have detailed information and understanding of the dam history, past performance issues and a good perspective on perceived changes at the dam. It is important to include them in risk analysis activities to benefit from their knowledge of the dam and it is very important for them to gain an understanding of potential failure modes at the dam, specific locations at the dam where potential failure modes might develop and the initiating mechanisms for the potential failure modes. This will allow them to more effectively monitor the dam. Likewise the results of risk analyses and the decisions and rationale used in risk assessment and risk management need to be provided to these personnel such that they have a full understanding of the outcome of the risk process.

2. **Local Level of an Organization**

Supervision and management of the operation of a number of projects and dams is usually the responsibility of a local office within a dam safety organization. These offices have the responsibility for the staffing for routine operation and maintenance of the projects and dams under their purview as well as inspection and monitoring of the dams. In addition they are often

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responsible for implementing structural and non-structural actions which may be specified as the outcome of the risk informed decision analyses. Often these local offices cover a number of facilities and manage a staff that must distribute their time between several sites. Local office personnel, as appropriate, also need to be consulted and included in risk analyses relative to failure modes and dam performance either because they have previously been assigned to dams under their purview and have an intimate historic knowledge and/or they have a broader perspective by virtue of being associated with all the projects and dams under their responsibility. With respect to communicating the findings from the risk analyses, and the decisions from risk assessment and risk management, the local office is typically the key intermediary between the desired objectives of the organization's dam safety office and the field site where these outcomes are to be effected.

3. **Technical Elements of an Organization**

Detailed communications are required among the technical staff (including consultants and contractors) performing the basic analytical studies and evaluations, the persons performing the risk analyses and the staff performing the risk studies who will be reviewing studies, analysis reports and risk analysis reports and making their assessments on specific dams and dam safety issue evaluations. The reports prepared by each previous study level will need to include sufficient detail so the primary reviewers (as well as analysts in future years) can understand assumptions made, detailed results of studies, analyses and risk analyses and the technical basis for overall findings. Further, these results made be called for at any future stage in the process (risk management, stakeholder review, etc.) and thus good documentation is essential. Briefings are typically performed for technical staff on the results of studies, risk analyses, the overall findings and the dam safety case for proposed actions. Briefings may also be performed for consultant review boards, which provide an independent review of studies and findings. At this level the communication will be the most demanding technically.

4. **Decision making Level of an Organization**

Decision makers need to have a general understanding of the potential failure modes at a dam, the results of studies and analyses performed, the risk analysis results and the dam safety case. Decision makers have the responsibility for formally accepting dam safety actions and must be convinced that the proposed actions are warranted and appropriate. Summary technical information is typically presented in briefings for decision makers and the detail needs to be sufficient to support the key findings and dam safety case. Individuals who have the responsibility for setting priorities within an organization will also need to understand the basis and urgency of dam safety actions at a given dam. This is needed to prioritize actions across an entire inventory.

B. *Communications with Stakeholders*

Risk communication with and including stakeholder or owner participation are important elements to be successful. Risk communication and stakeholder participation should ensure: (1) responsible and affected stakeholders will be partners and afforded the opportunity to participate in decisions that affect them, and (2) communications regarding potential inundation hazard, consequences, and shared solutions will be open, transparent and understandable.

It may be helpful to include individuals from stakeholder organizations as observers in the risk analysis and especially in the risk assessment meetings. This will allow those individuals to gain a better understanding of the basis of the risk analysis estimates, the subsequent findings and the rationale on which a decision is made. They will typically be interested in the rationale behind proposed dam safety and will want to ensure that the

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chosen actions are appropriate and efficient. It will also be helpful to explain the overall dam safety process used and explain the risk guidelines that were used in the risk assessment. Funding partners may enlist consultants to review reports, attend briefings and interact with technical staff. Detailed technical reports and briefings may need to be provided for consultants

C. *Communications with the organizations and the public impacted by the dam*

Communications should also be provided proactively for organizations and the public that will be, could be, or consider themselves impacted by a dam failure or by dam safety actions that will restrict or modify the operations at the dam. These communications should be initiated at the planning or investigation stage so as to inhibit development of erroneous information and rumors. Such presentations need to be appropriately technical – conveying the technical information in a manner that conveys the key issues and concerns at the dam, the potential impacts of a dam failure, the proposed actions to address the issues/concerns and the impacts of these actions on organizations and the public and the costs and schedule for the dam safety actions, but avoids technical jargon and detailed technical presentations. Information should be presented in a clearly understandable manner but not in a way that is condescending to the audience. The diverse audience that attends the public and stakeholder meetings may will include persons who can fully comprehend the technical content being presented and a sure fire way to alienate the audience is to presume they are incapable of understanding the work that is planned or has been done. Technical staff should be available to answer detailed technical questions from individuals with technical backgrounds that may attend the briefing. Organizations may have security concerns related to information that is presented in these general briefings or public meetings and the presentations may have to be adjusted to take this into account.

The following principles apply to risk communication:

19. Enhance communication to the public and internally within dam owning and regulating organizations (EMAs).
20. Emergency Action Plans and communication with the public is an important and integral aspect of reducing risk to life.
21. Communications should be open and transparent.
22. When presenting dam safety issues at a given dam, focus on the benefits and the risks posed by infrastructure.
23. Integrate risk communications early in the process of responding to dam safety issues.
24. Provide context for risk communications (compare with other risks).
25. Focus communications on actions that individuals/organizations need to take.
26. Discuss uncertainty in risk estimates and the dam safety case:
 - a. What you're certain of.
 - b. What is likely but not certain.
 - c. What is possible but not likely.

VII. Appendix A – Guideline on Risk Terminology

To facilitate the cooperative agreement with respect to all elements of Risk Based Decision Analysis it is extremely valuable to use common terminology and have a common understanding of that terminology. It is recognized that this is not a simple task as the words related to dam safety risk have been used in different ways by the member agencies over the years since their initial application over thirty five years ago, however, toward the end of establishing consistency in terminology, the guideline provides definitions of the terms given below that are used in Risk Management, Risk Assessment, Risk Analysis and Risk Evaluation.

Risk – The product of the likelihood of a structure being loaded, adverse structural performance, (e.g. dam failure) and the magnitude of the resulting consequences.

Risk Analysis / Risk Estimation – A qualitative or quantitative procedure that identifies potential modes of failure and the conditions and events that must take place for failure to occur and then obtains (for a quantitative analysis) a numerical estimate of the risk of adverse consequence multiplying the probability of load times the probability of dam failure given the load times the magnitude of adverse consequence given dam failure.

Risk Assessment – The process of considering the quantitative or qualitative estimate of risk along with all related social, environmental, cost, temporal and other factors to determine a recommended course of action with regard to mitigating or accepting the risk.

Risk Management – actions implemented to communicate the risks and either accept, avoid, transfer or control the risks to an acceptable level considering associated costs and benefits of any action taken.

Risk Evaluation – Risk evaluation is the qualitative or quantitative description of the nature, magnitude and likelihood of the adverse effects associated with a hazard. A risk evaluation often includes: one or more estimates of risk; risk description; risk management options; economic and other evaluations; estimates of changes in risk attributable to the management options.

Residual Risk – Risk remaining at any time.

Risk Governance – The process of risk-informed decision-making and the process by which risk-informed decisions are implemented.

Uncertainty - Uncertainty is the result of imperfect knowledge concerning the present or future state of a system, event, situation, or population under consideration.

Tolerable Risk - A risk within a range that society can live with so as to secure the benefits provided by the dam. It is in the range of risk that we do not regard as negligible or as something we might ignore, but rather as something that we need to keep under review and reduce it still further as we can.

Dam Failure – Failure characterized by the sudden rapid and uncontrolled release of impounded water. 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.

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Potential Failure Mode – A way that dam failure can occur (i.e., the full sequence of events from initiation to failure) for a given loading condition.

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