GUIDELINES FOR ACHIEVING PUBLIC PROTECTION IN DAM SAFETY DECISIONMAKING

UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
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I. Introduction

Purpose of Guidelines - The Bureau of Reclamation (Reclamation) is responsible for about 370 storage dams and dikes that form a significant part of the water resources infrastructure for the western United States. As the owner of these facilities, Reclamation is committed to providing the public and the environment with adequate protection from the risks which are inherent to collecting and storing large volumes of water for later distribution and/or release. This document presents:

- The basis and guidance for a risk-based approach to decisionmaking
- Guidelines for evaluating risks at Reclamation dams
- Guidelines for developing and presenting the risk estimates
- Guidelines for interpreting/assessing the risk results
- Example actions that can be taken to address risk at dams
- Guidelines for maintaining a focus on risk reduction when implementing agency actions

The guidelines are intended to ensure adequate and consistent levels of public protection when evaluating and modifying existing dams and appurtenant structures and when designing new dams and/or structures.

Considering a Full Range of Loading Conditions - Historical design and analysis methods have focused on selecting a level of protection based on loadings from extreme events and conditions. These extreme events comprise the upper bound of loadings considered to be reasonably probable. The civil engineering profession generally agrees that dams and dikes designed to withstand extreme loadings meet an acceptable standard of public safety. In addition to ensuring public safety for extreme events, Reclamation also is committed to providing public safety for smaller events and loading conditions, which occur more frequently. For example, an enlarged spillway designed for a probable maximum flood loading condition may increase the risks to the public for lesser events. Risk assessment provides a framework for addressing the most effective way to provide public protection over the full range of loading conditions.

Need for Probabilistic Methods - As a water resources management agency, Reclamation strives to provide decisionmakers with pertinent information that is founded upon current or emerging water resources management and public safety practices. Over the past decade, there has been an increasing trend in water resources analysis toward using probabilistic design methods to evaluate the effectiveness of expending funds for enhancing public safety. There has also been greater recognition that even the most restrictive design standards result in some likelihood of failure even though the likelihood may be very small.

Application - This document addresses the incorporation of risk-based evaluations into Reclamation's dam safety decisionmaking process to help assess public risks and allocate resources. While there are many issues that may be evaluated in a risk context, this document focuses on the life loss and the public trust components of decisionmaking. Similar applications of risk-based analysis techniques may be used to address economic consequences within the

framework of the *Principles and Guidelines* for water resources planning.[1] Risk-based analysis may also be used to evaluate environmental and social issues in accordance with the National Environmental Policy Act (NEPA) by addressing the likelihood of the possible outcomes that may result from the various loads that a dam experiences. The implementation of risk-based analysis should consider both usefulness and cost effectiveness in its use.

[1] Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies from the Water Resources Council, March 10, 1983.

II. Risk Assessment Framework for Dam Safety Decisionmaking

A. Background

The mission of the Reclamation Dam Safety Program is:

> "To ensure that Reclamation facilities do not present unreasonable risks to the public, public safety, property, and/or the environment."

The Dam Safety Program is authorized under the Reclamation Safety of Dams Act of 1978.[2] This Act was passed in response to several dam failures in the 1960's and 1970's, including the failure of Teton Dam, a large Reclamation storage dam. The Act provides for action to be taken when it is determined that a structure presents an unacceptable risk:

> "In order to preserve the structural safety of Bureau of Reclamation dams and related facilities, the Secretary of the Interior is authorized to perform such modifications as he determines to be reasonably required."

To determine the risks associated with its structures, Reclamation has established procedures to analyze data and assess the condition of its structures. Prior to the failure of Teton Dam, consideration of dam safety issues was addressed though periodic examinations and project specific requests for Congressional funding to make necessary modifications to dams. The failure of Teton Dam demonstrated a need for a more comprehensive approach to evaluating and addressing dam safety issues.

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. While the Federal Guidelines 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."[3]

Reclamation has established a risk-based framework to meet the objectives of its program, the Dam Safety Act, and the Federal Guidelines. Risk-based procedures are used to assess the safety of Reclamation structures, to aid in making decisions to protect

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[2] The Reclamation Safety of Dams Act of 1978, Public Law 95-578.

[3] Federal Guidelines for Dam Safety, Ad Hoc Interagency on Dam Safety, Federal Coordinating Council for Science Engineering and Technology, Washington, D.C., June 25, 1979.

the public from the consequences of dam failure, to assist in prioritizing the allocation of resources, and to support justification for risk reduction actions where needed. Risk assessment for dam safety decisionmaking integrates the analytical methods of risk-based analysis along with the sound professional judgment of engineers, contractors and review boards in determining reasonable actions to minimize risk at Reclamation facilities.

B. Terminology

The following terminology is provided for terms that are used throughout these guidelines for defining the risk-based framework for dam safety decisionmaking:

Risk – The product of the likelihood of an adverse event and the consequences of that event

Failure Mode - A potential failure mode is a physically plausible process for dam failure resulting from an existing inadequacy or defect related to a natural foundation condition, the dam or appurtenant structures design, the construction, the materials incorporated, the operations and maintenance, or aging process, which can lead to an uncontrolled release of the reservoir.

Risk Analysis – A procedure to identify and quantify risks by establishing potential failure modes, providing numerical estimates of the likelihood of an event in a specified time period, and estimating the magnitude of the consequences. The risk analysis should include all potential events that would cause unintentional release of stored water from the reservoir.

Risk Evaluation – The establishment of Reclamation guidelines for agency response to estimated risks.

Risk Assessment – The use of risk estimation for a given dam in the decisionmaking that leads to agency response according to risk evaluation guidelines.

Consequences – Estimated losses that result from an adverse event leading to a dam failure scenario.

Failure Probability, Consequences, and Risk Estimates – The mean values calculated from Monte Carlo or similar analyses that include explicit treatment of input uncertainty. Also, the calculated numerical values when single point estimates are used in the calculations and the point values are considered reasonable and plausible estimates of the mean rather than extreme values in a range. These estimated mean values are also called the expected values. *(Note: This definition must be applied in order to achieve effective and consistent application of these guidelines.)*

C. Risk Framework

Risk analysis is a tool that enables technical specialists and decisionmakers to better understand possible failure mechanisms and the elements of risk involved in the various issues related to dam safety. It provides an overall picture of risks, the potential impacts of proposed actions, and the resulting costs (economic, social and other). The results of risk analyses can contribute to efficient accomplishment of the dam safety program by quantifying engineering judgments that allow for the evaluation of:

- Factors contributing the greatest risk at a given site,
- The facilities with the greatest risk,
- Identification of additional analyses and/or data collection that are needed to better understand critical uncertainties,
- Anticipated risk reduction effectiveness of alternative courses of action,
- Allocations of dam safety program funds that will contribute the greatest overall risk reductions.

The risk framework consists of several steps leading to agency decisions regarding appropriate actions to be taken to address dam safety risks at Reclamation's high- and significant-hazard dams. These steps are summarized as follows:

Risk Identification – As part of the ongoing dam safety evaluations for each high- and significant-hazard dam, Reclamation identifies the conceivable modes of dam failure. These failure modes are then monitored (through performance monitoring and examinations) for any indication of changes in performance that would be indicative of a dam progressing toward a failure condition or toward a significant risk to the public. If such indications are found, the issue is referred for further evaluation of the estimated risk. If failure modes are deemed likely, action to reduce risk may be taken.

Risk Estimation – Once a dam safety issue has been identified, it is necessary to assess and quantify the risk to the public as information to be used by the decisionmakers. The quantification of risk involves the estimation of the likelihood (probability) of an unintentional release of stored water and an estimation of the consequences resulting from the unintentional release. To facilitate developing the risk estimates, it is frequently convenient to break the estimating process down into three components including: estimating the likelihood of an initiating condition existing or an event occurring, estimating the likelihood of an unintentional release of the reservoir given the event or initiating condition, and estimating the consequences (life loss) given the unintentional release of the reservoir.

Risk Evaluation – Once risks have been estimated for a dam, decisionmakers need a framework for evaluating the risks to determine if action is required to reduce risks. There is currently no commonly accepted industry standard for determining what risks are considered acceptable.

The guidelines portion of this document provides for evaluation of risk by two measures. The first measure, the annual probability of failure, addresses the public's expectation that Reclamation dams should not fail by evaluating the probability of an unintended release of the reservoir. It also addresses the expectation that risk to the most exposed individual will be managed. The second measure addresses the expected value of life loss expressed on an annual basis which combines the annual failure probability estimates with estimates of the expected life loss consequences given a dam failure. The first measure addresses agency and individual risk, while the second measure addresses the life loss component of societal risk.

Risk Reduction Actions – When decisionmakers have determined that a risk reduction action is required, there are usually a number of prudent alternative actions that can be taken. Dam safety decisionmaking involves the selection of an appropriate course of action for a given issue based on the magnitude of the risk, the degree of confidence in (or uncertainties associated with) the estimated risk, and the likelihood of additional information providing a significantly enhanced understanding of the risks associated with the identified issues.

Roles of analysis approaches - Although risk-based and standards-based (design standards, codes or criteria) approaches are often considered to be competing approaches, each have a role in Reclamation's decisionmaking process. Risk assessment is a diagnostic tool used throughout the evaluation, design, and construction process that helps decisionmakers formalize and document dam safety decisions. Standards are used to ensure that the selected corrective actions are well designed and implemented. In other words, risk-based approaches help decision makers choose the appropriate courses of action while standards-based approaches assure sound implementation of those actions.

D. Decisionmaking

Policy - Reclamation policy for dam safety decisionmaking delegates decisionmaking responsibility to the Regional Directors in collaboration with the Chief, Dam Safety Office and the appropriate Area Manager.[4] The Technical Service Center (TSC) staff provides significant technical advice that is critical to decisionmaking. The risk framework serves as a tool for aiding decisionmakers in the determination of needs for risk reduction actions as well as the evaluation of different risk reduction actions that could be taken to address the identified issues.

Public Trust Responsibility - Decisionmaking to accomplish the Dam Safety Program is complex and must consider risk to the public as well as economic, environmental, and cultural impacts. Thus, it is difficult to be prescriptive when developing guidance for making decisions. While the technical analysis of risks associated with a dam can not become the sole decisionmaking factor, it must be recognized that addressing these risks in a technically consistent and timely fashion is an important part of sustaining the public's trust in Reclamation to manage these facilities in the best interest of the nation.

[4] Decisions Related to Dam Safety Issues, Reclamation Manual / Policy FAC P02, Bureau of Reclamation, Denver, Colorado, June 23, 1998.

This public trust responsibility includes operating Reclamation facilities with reasonable assurance of the safety of persons in the vicinity of and downstream of the dams.

Process - Dam safety decisionmaking is similar to many other aspects of water resources management in that decisions regarding reasonable courses of action are not always initially agreed upon by all stakeholders. The most important part of the decisionmaking process is recognizing that it will generally involve building consensus regarding the appropriate actions to be taken. However, in the event of an emergency, the time for developing consensus may be severely shortened or nonexistent. Such a situation would require the Regional Director to act quickly to avoid or minimize consequences.

III. Public Protection (Risk Evaluation) Guidelines

Measures of Risk - These guidelines focus on two assessment measures of risks related to Reclamation structures: 1) the probability of a dam failure and 2) the life loss consequences resulting from the unintentional release. The annual probability of failure guideline addresses agency exposure to dam failure. As a water resource provider, Reclamation must maintain and protect its dams and dikes that store water. The second measure addresses the life loss component of societal risk. Protection of human life is of primary importance to public agencies constructing, maintaining, or regulating civil works.

Risk Analysis Methods - Reclamation's risk analysis process involves the development of event trees that identify all of the known and potential events, states of nature (existing conditions, site characterization, etc), dam responses, exposure conditions, and consequences. The overall risk from the facility is defined as the accumulation of all risks associated with each of the possible paths through the event trees. The methods to analyze the risks associated with annual dam failure probability and life loss are briefly described in the following two sections. Additional information on the methodology for performing risk analysis can be found in *"Dam Safety Risk Analysis Methodology."*[5]

Potential Applications - Although these guidelines focus on life loss as a dam failure consequence, other consequences, such as environmental and economic consequences, may be applied on specific projects where the decisionmaking process would be enhanced by presentation of the entire breadth of consequences and risks. Economic and/or environmental risk assessment may be performed when the potential for life loss does not provide sufficient or appropriate input for a decision regarding modification of a structure.

A. Evidence of a Developing Failure Mode

If there is evidence of a developing failure mode, there is a clear need to take action to reduce risk. These situations should be brought to the immediate attention of the dam safety decisionmakers to assure a timely response by the agency. Once the evidence is determined to be credible, efforts should focus on those risk reduction actions that can be taken to quickly reduce the potential for life loss or an unintended release of the reservoir regardless of any risk estimates.

B. Annual Probability of Failure (Previously Tier 2)

Measurement Purpose - To manage an effective Dam Safety Program on behalf of the Federal government and to assure public confidence in the performance of public works, dam failures and associated large consequences need to be avoided. A high level of national safety and stewardship of public assets is expected of Reclamation as an agency

[5] Dam Safety Risk Analysis Methodology, Bureau of Reclamation, Denver, Colorado, Version 3.3, September 1999.

specifically entrusted to manage a large inventory of dams. Unintended release of the reservoir can cause significant downstream damage and disruption to routine activities. Once an unintended reservoir release occurs, public trust is compromised and public expectations may impose severe and costly constraints on projects. The greater the inventory of dams and the time of exposure, the more difficult it becomes to ensure that the agency will not experience a dam failure.

Measurement Definition - For comparison to this guideline, the annual probability of failure is defined as the probability of a structural failure or condition that results in an unintentional release of the reservoir that would be expected to result in loss of life. The annual probability of failure is totaled for all specific loading conditions (seismic, static, hydrologic, improper operation, etc.) The probability of events that are not expected to cause life loss are not included, even though there may be some unintended loss of reservoir storage. For example, if a structure accommodates large flows through rockfill without breaching and without causing life loss, then the flow condition would not be included in the probability of failure calculation. Events or conditions that can result in an unintentional reservoir release are referred to as failure modes. These include failure due to loadings from normal and extreme events.

Guideline - To ensure a responsible performance level across the inventory of Reclamation Dams, it is recommended that decisionmakers consider taking action to reduce risk if the estimate of annual failure probability exceeds 1 chance in 10,000. Table 1 provides guidelines to evaluate the need and urgency to implement risk reduction activities based on the annual failure probability estimates:

Table 1. – Guidelines to evaluate Annual Probability of Failure Estimates	
Estimates for annual probability of failure > 0. 0001	The justification to implement risk reduction actions increases as the estimates become greater than .0001. Actions considered reasonable and prudent should be considered for implementation when the annual probability of failure estimate is in this range. A variety of possible actions may be appropriate (see Section IV.D).
Estimates for annual probability of failure < 0. 0001	The justification to implement risk reduction actions diminishes as the estimates become smaller than .0001. Risk reduction action costs, uncertainties in the risk estimates, scope of consequences, operational and other water resources management issues play an increased role in decisionmaking. Actions considered reasonable and prudent should be considered for implementation when the annual probability of failure is in this range.

C. Estimated Risk (Annualized life loss - Previously Tier 1)

Measurement Purpose - Reclamation's primary dam safety concern is to ensure that its structures do not cause life loss. The estimated risk is calculated for each specific loading category (seismic, static, hydrologic, improper operation, etc.) at a dam based on the estimated life loss from dam failure.

Measurement Definition – For dam safety decisionmaking, risk of life loss is measured as the product of the probability of dam failure and the consequences (life loss) associated with that failure. This product is the expected annualized life loss at a given dam for a given loading condition and is referred to as the estimated risk of life loss.

Guidelines - Table 2 provides guidelines to evaluate the need and urgency to implement risk reduction activities based on the estimated risk:

Table 2. – Guidance for Estimated Risk	
Estimated risk is portrayed to be >. 01 lives/year	Reclamation considers that there is justification for taking expedited action to reduce risk. While there is a full range of possible risk reduction actions that can be taken (see section IV.D), Reclamation should focus on those that can quickly reduce risk or improve understanding of the uncertainties associated with the risk. As confidence increases that the risk is in this range, actions considered should concentrate more on reducing the risk than reducing the uncertainties. Any reassessment of the risk should be done prior to increased storage if at all possible, and every effort should be made to complete the reassessment within 90 days of determining the need for expedited risk reduction action.
Estimated risk is portrayed between .01 and .001 lives/year	Reclamation considers that there is justification for taking action to reduce risk. When the range of risk estimates falls in this range, there are a wide variety of possible actions which may be appropriate. However, the actions can be scheduled into the dam safety program and coordinated with other needs at the facility or at other facilities. Actions to reduce risks should be implemented on a schedule that is consistent with budgeting and appropriations processes. Typically, risk reduction should be accomplished within 7 years of a decision that risks need to be reduced. When there is an indicated need for risk reduction, the time spent on additional loading definition, data collection, and risk assessment should be completed in a reasonable timeframe. While it is desirable for this timeframe to be within a year, other times may be considered reasonable by decisionmakers based on the severity of the identified risks. Decisions on adequate time frames should be documented in appropriate decision documents.
Estimated risk is portrayed to be < .001 lives/year	The justification to implement risk reduction actions or conduct additional studies diminishes as estimated risks become smaller than .001. Risk reduction action costs, uncertainties in the risk estimates, scope of consequences, operational and other water resources management issues play an increased role in decisionmaking. Actions considered reasonable and prudent should be considered for implementation when the risk is in this range.

Risk to Small Populations - When life loss estimates are low (less than 10) for a given

loading category, a threshold estimated risk of .001 can potentially expose a small population to failure events with relatively high probabilities. Risk to an individual from dam failure for these cases may be similar to other societal risks such as auto accidents and disease. Accordingly, risks associated with a Reclamation storage facility could contribute significantly to the life risks of an individual in the exposed population. In these cases, the guidelines related to annual probability of failure (section IV.A) serve as an upper limit of exposure to such small populations.

IV. Determining Appropriate Actions

A. Development and Presentation of Risk Estimates

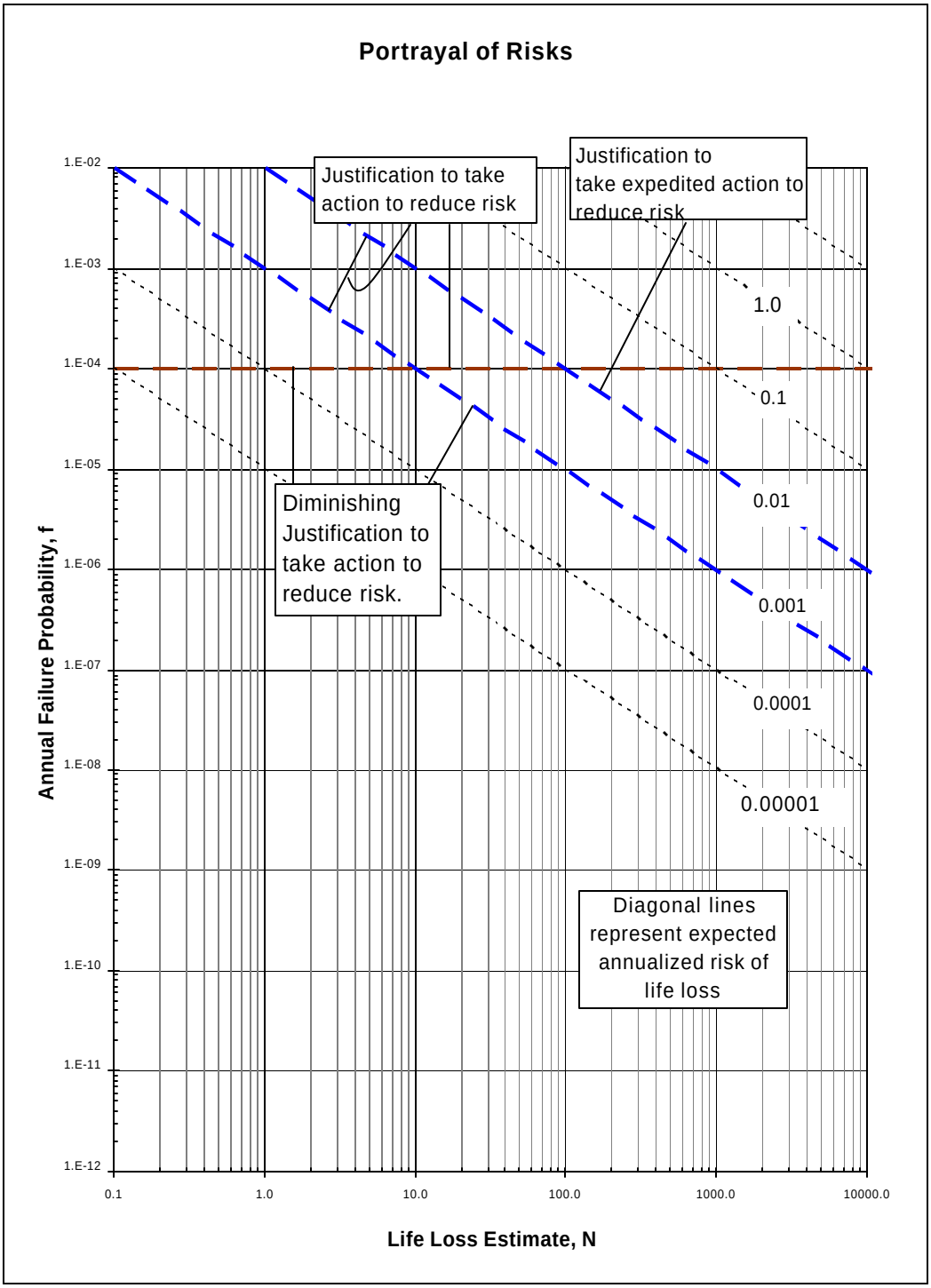
Use of Risk Estimates - Risk analysis provides a means to quantify judgment and to identify the parameters that contribute to risk at a site. The intent of a risk assessment is to review the failure modes for a dam, to decompose the failure modes into separate events, to assign probabilities to the events, and to provide a range of risk estimates so that risks can be compared to these guidelines. Valuable outcomes of the risk assessment include an improved understanding of the critical issues at a dam and a clearer identification of the issues that are the most significant contributors to risk. This knowledge can be used to focus attention on those issues, which, if mitigated, will provide the greatest reduction of risk to the public.

CFR Risk Estimates - Since the risk estimating process during the Comprehensive Facility Review (CFR) is not a detailed team effort, it may have a higher level of uncertainty than an issue evaluation risk analysis. The results of a CFR risk assessment should be presented as the mean estimate or the expected value of risk. If the senior engineer feels that significant assumptions need to be made, resulting in more than one possible scenario to be considered, a range of risk estimates may be presented. If a range of estimates is provided, the CFR must clearly state the specific assumptions or reasons that form the basis of the range of estimates. If the risk estimate is presented as a single point, decision makers should be cognizant of the fact that the estimate actually has a degree of uncertainty associated with it.

Issue Evaluation Risk Estimates - Detailed team risk analyses should also address the uncertainty associated with the risk estimate. Typically in issue evaluation team risk analyses, probability density functions are assigned to the estimates in an event tree. Techniques such as Monte Carlo simulation can be used to show the variability in a number of trials that sample the assigned probability density functions. The risk estimate is defined to be the arithmetic mean of the values computed for all trials. Sensitivity studies may be performed by assigning other reasonable density functions and noting the change in both the variability of the trial estimates and the calculated mean risk estimate. Such sensitivity studies provide the decisionmakers with an estimate of a range of the risk estimate based on the risk model used by the team. If the scatter plots of the Monte Carlo calculation trials are presented, it should be carefully explained that the individual points are not risk estimates as defined in Section II.B. These scatter plots may be useful in analysis and may help communicate the key factors influencing the risk estimates.

Displaying Risk Estimates - The range of risk estimates (annual probability of dam failure and expected annual life loss) should be presented for each load category on an f-N diagram as shown in Figure 1. The f-N diagram illustrates the probability of dam failure, the potential consequences, and the expected annual life loss risk associated with a given load category on one diagram. The guidelines for considering risk reduction action are illustrated as dashed bold lines on the f-N diagram.

Figure 1. - The f-N Chart for Displaying Probability of Failure, Life Loss, and Risk Estimates



Communicating the Basis of Risk Estimates - It is important to note that the key objective of the risk analysis is to communicate the current understanding of risk to the decisionmakers. Decisions will be facilitated by elaboration on the reasons the risk might be higher or lower and the additional information that might better define the risk. For example, the range of risk estimates might not be continuous if there is an important lack of information or if there are alternate interpretations of the available information about a structure. There could be one range of risk estimates that is high and another that is low with the difference being the assumption about the information that is lacking or the interpretation of the available information. This sort of risk estimate communication can be very useful to the decisionmakers when proposals for gathering additional data or for more detailed technical analysis are considered.

B. Assessment (Use and Interpretation) of Risk Results

Action Based Decisionmaking - Dam Safety issues may be identified as Reclamation operates, maintains, monitors, inspects, or analyzes a structure. When issues arise, further data collection, investigation, and related analysis may be required to better understand the public safety or economic implications. Reclamation will address the identified issues by taking an action, prioritizing and scheduling an action, or by documenting a decision that no action is necessary. In general, many issues are raised without implications on continued operation of the facility. The dam safety decisionmakers should consider the potential severity of issues being addressed in the context of the dam safety program objectives and determine if continued normal operation of the facility is appropriate. If a decision is made to continue normal operations while issues are being addressed, then that decision should be documented.

Prioritization - Reclamation has limited financial resources available to address issues. It is critical to not only identify future actions but also to identify the priority or the time frame associated with these actions. The priority for initiating actions to address risks depends in part on available resources and on the risks throughout Reclamation's dam inventory. The intent is to make the greatest reduction in risk throughout the inventory of Reclamation dams within the resource limitations of the program while at the same time assuring that no dam presents an unreasonable risk.

Uncertainty - The quantification of risk estimates is dependent on data and analysis regarding the design, construction, and current condition of a dam, as well as the identified loads that the dam could be subjected to over its operating life. All of this information has some level of uncertainty associated with it. It is acknowledged that the quantification of risk estimates is subjective and is a function of group dynamics, the experience and associated judgment of group members, and the available information for a dam. Thus, uncertainty in the risk estimates is expected. As a consequence, there can be a range of actions that may be suggested for a given range of risk estimates.

Assessing Ability to Reduce Uncertainty - When making a decision regarding future actions, one should consider the risk estimates, the issues most influencing the risks, the

sensitivity of the risks to particular inputs, the cost of additional actions, and the potential for reducing uncertainty. Uncertainty may be reduced by performing additional actions such as collecting more data, by performing more analysis, or by performing a more detailed analysis of the risks. However, there are occasions when additional efforts may not result in significant reduction in uncertainty. It is important to recognize when this is the case and consider the anticipated value of the additional efforts to reduce uncertainty as a factor in selecting a course of action.

Risk Estimate Ranges (range of means) Straddling the Guidelines - In gathering the information necessary for dam safety decisionmaking, the decisionmaker will never have complete or perfect data on which to base the decision. Accordingly, there is some degree of uncertainty in the risk estimates for each dam. When significant uncertainties or assumptions related to a lack of data or interpretations of data result in a range of risk estimates, the results may straddle the guideline values with portions of the risk estimates range portrayed both above and below the guidelines. In these cases, it is important for decisionmakers to assess the portion of the risk estimate range that exceeds the guidelines to determine if it is significant enough to warrant further action or studies. The entire range should be used to assess the need for future actions as well as an aid in setting the priority for initiating the actions. If the range extends into the zone that justifies expedited risk reduction, studies to better define the risk should be the minimum response of the agency.

Level of Analysis Considerations - Because CFR analyses are not detailed team efforts, decisions based on CFR-based risk assessments are typically related to improvements in monitoring, collection of additional data, or performance of additional analyses to reduce uncertainty or improve confidence in the risk estimates. Decisions to change operations or initiate modifications are generally not made as a result of these analyses.
Issue evaluation risk analyses are more extensive analyses of risk and draw on a broader range of expertise. These analyses may require additional data collection, additional analyses, and include a more detailed breakdown and analysis of risks. Risk estimates developed during this activity are often computed using a Monte Carlo simulation and should include sensitivity studies to determine a potential range for the risk estimate.

Risk Reduction Objective - It is important to reduce risk as low as can reasonably be achieved if it is decided to pursue a risk reduction action. As a result, it is desirable to lower the entire range within which the risk estimate would be expected to fall given the uncertainties. An evaluation of the effect of modification alternatives on the range of the risk estimate will enter into the selection of the preferred alternative. In other words, selection of a preferred alternative should focus on moving the range of the risk estimate sufficiently below the guidelines to assure that the dam safety issue doesn't resurface due to slight differences in interpretations of the risk.

Consideration of Future Developments - Future growth in the downstream flood plain, increases in the loading estimates, and changes in the state-of-the-art, may result in increases in risk estimates. Thus, the more risk reduction achieved, the less likely it becomes that future studies will conclude that the risks no longer meet Reclamations guidelines. Risk reduction goals should be considered on a cost versus risk reduction

basis. Ideally, a menu of options, associated costs, and impacts on risk should be considered by the decisionmakers so that prudent decisions can be made.

C. Large Downstream Populations

When the probability of a given loading category is relatively high and there is high potential for downstream life loss, a very low probability of unintended release is required by these guidelines. In such cases, Reclamation focuses on ensuring that there are sufficient protective (defensive design) measures incorporated into the structure. These protective measures either increase confidence in the structure's ability to perform satisfactorily without unintended releases, or increase confidence in Reclamation's ability to detect adverse performance with sufficient lead time to intervene and either prevent an unintended release or provide adequate warning to the public.

In some cases, risk reduction actions may be taken to increase confidence in the performance of the structure even though the dam shows no significant signs of adverse performance. In these cases, decisionmakers should work with the technical experts to ensure that there are sufficient redundancies in the design and operations of the facility to instill confidence in the future performance of the structure.

D. Examples of Alternative Actions

With increased justification for action, there is a need to propose alternative actions that will adequately address the risk and/or probability of failure at the dam. It is important to recognize that there is a broad range of actions that can be taken. These actions can range from further investigations to better understand the uncertainties associated with the risks to decisions to modify structures. In many cases, the chosen course may involve a combination of several actions.

Dam safety decisionmaking generally involves the selection of an appropriate course of action for a given issue based on the magnitude of the risk, the degree of confidence in (or uncertainties associated with) the estimated risk, and the likelihood of additional information providing a significantly enhanced understanding of the issues. The state of knowledge regarding the dam safety issues can lead to a variety of possible actions. While the risks associated with each individual facility pose a unique situation, the following are some of the types of actions which can be taken to either improve Reclamation's understanding of the uncertainties associated with the estimated risk, or to improve confidence in the ability of a structure to perform satisfactorily.

Risk Management Activities:

> **Refine Analyses** – If a risk estimate warrants action primarily due to uncertainties in key elements contributing to the risk, decisionmakers may consider gathering additional information in a timely fashion to assist in quickly reassessing the risk. In pursuing this activity, the decisionmakers should satisfy themselves that there are no immediately developing failure modes. Any expedited reassessment of the risk should be done prior to increased storage if at all possible, and every effort should be made to complete the reassessment within

90 days of determining the need for action. If the reassessment indicates expedited risk reduction action is needed, a decision concerning the risk reduction measures should be made and documented.

Reservoir restrictions - While a reservoir restriction is technically an operational change, it can result in a significant and immediate change in the risk at a dam. The risk reduction results from a reduction in the loading condition and the failure probability. Another benefit is that the reduced storage and reduced head leads to less potential for adverse consequences in the event of poor performance of the structure. However, the loss of storage can have a dramatic impact on water users and the environment. Therefore, consideration of a reservoir restriction requires consideration of both the expected reduction in risk and the certainty of the lost project benefits that accrue from limiting storage in the reservoir.

Increased monitoring - If the risks associated with a failure mode are such that successful intervention would likely be possible or better warning could be provided to local authorities, a potential course of action is to improve Reclamation's ability to detect the existence of the conditions which would be indicative of the failure mode developing (i.e. seepage, deformation, etc.)

Operational changes - In some cases, risks can be reduced at a dam by making changes in the operational and/or maintenance practices at a dam. Examples include establishing minimum gate openings to minimize potential for cavitation, checking gates for drift from their set positions, or alternate procedures for filling reservoirs to lower risks at critical times of the year.

Revised Emergency Action Plan (EAP) - The potential for adverse consequences can be minimized by reviewing the potential failure modes and by developing clear guides to decisionmaking for the types of emergency situations that can be envisioned. Existing EAPs have been developed to detect emergency events based on site specific loading conditions. If a new loading condition or potentially adverse response has been identified for a dam, then the EAP initiating conditions, emergency response levels, expected actions for each response level, and hazard specific appendices can be revised to reflect the current conditions or concerns at the facility. While this course of action will not reduce the probability of an adverse response of the structure, it can help to ensure that people understand the risks at the dam and know how to respond appropriately. This may result in a reduction of the life loss risk.

Loading definition - An important part of understanding risk lies in determining the frequency with which unlikely events affect a dam. In some cases, it is beneficial to gather data that will improve the understanding of the frequency-magnitude relationship of the loading conditions that can potentially lead to failure modes. This information would be used to reanalyze the risks.

Data collection - When there is a lack of knowledge of key properties of a facility, there can be considerable uncertainty in its performance. A prudent

action may be to collect information so the performance of the dam can be better predicted. This additional data would be used to reanalyze the risks.

Structural Modifications - When non-structural actions are not expected to adequately address the risks at a facility, structural modifications to the dam may be considered when additional information will not change the risk outcome. The intent of such modifications is to increase confidence in the satisfactory performance of the structure under the applied loading conditions. Throughout the design and construction process, the risks should be evaluated to assure that design and construction decisions are consistent with the risk reduction objectives.

E. Formulation of Appropriate Risk Reduction Alternatives

Role of Risk Estimates - A key to formulating risk reduction alternatives is using the risk analysis information to assure that proposed alternatives will result in effective risk reduction. When developing the alternatives, the event trees should be reviewed to evaluate which events or conditions are the most significant contributors to the overall risk and/or probability of failure. In some cases, very significant risk reductions can be accomplished by focusing on a specific event or condition. In other cases, with multiple sources of risk, several issues may have to be addressed simultaneously in order to reduce risk and the associated probability of failure to appropriate levels.

Accumulation of Risk Over Time - During a risk reduction action, one should remember that Reclamation's goal is to reduce overall risk. This includes the sum of the risk from before, during, and after a risk reduction action. To minimize this total, it is important to proceed promptly with a risk reduction action when the risk values are high because delay in risk reduction increases the time accumulation of risk. Likewise, it is important to consider risks during construction, because these risks contribute to the accumulation of risk over time. Addressing an annualized potential for dam failure that could be relatively small by incurring a much higher probability of dam failure during the period of time that the dam is being modified may not be appropriate because it raises accumulated risk during the life of the dam to a level higher than would be incurred by not pursuing risk reduction action at all. This factor may influence the choice of modification alternatives and reservoir operations during construction. It should not be used to support a "do nothing'' alternative.

F. Unrecognized Risks

Reclamation recognizes that there will always be a potential for risk associated with unknown conditions at a dam that have not been recognized in the analysis. Therefore, an active examination, monitoring, and evaluation program should be in place to provide a mechanism for early detection of developing and/or potential problems. This early detection information should be used to assess changes in the perceived risks at individual dams, and to prioritize funding for the Dam Safety Program for risk reduction activities. The CFR process provides a framework for assuring that there is a periodic opportunity to reassess risk due to changes in the state-of-the-art of dam design or

changes in dam performance. If no such changes are applicable and no new risks are recognized, then the CFR risk assessment serves as a confirmation of previous risk analyses.