

FERC
Risk-Informed Decision Making Guidelines

Chapter 3

Risk Assessment

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ACRONYMS

AALL	average annual life loss
ALARP	as-low-as-reasonably-practicable
ANCOLD	Australian National Commission on Large Dams
APF	annual probability of failure
BOR	U.S. Department of the Interior, Bureau of Reclamation
CDA	Canadian Dam Association
CSSL	cost to save a statistical life
FERC	Federal Energy Regulatory Commission
HSE	Health and Safety Executive
NSW DSC	New South Wales Dam Safety Committee
TRG	tolerable risk guidelines
USACE	U.S. Army Corps of Engineers
VSL	value of a statistical life
WTP	willingness to pay to prevent a statistical fatality

CHAPTER 3

RISK ASSESSMENT

3.1 INTRODUCTION

3.1.1 General

Risk assessment is the process of considering the results from a quantitative or qualitative estimated risk analysis of an existing dam or project, along with all other factors related to a safety decision (FEMA, 2015). These factors can include the dam safety case, social/economic impacts, environmental impacts, constructability, and potential to do harm. The risk assessment is conducted to determine a recommended course of action (which may involve considering a range of options) for 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 (FEMA, 2015).

Typically the risk assessment and proposed recommendations are initially developed by the risk analysis team and then reviewed by a team of technically qualified and experienced reviewers, rather than a single individual. This team of reviewers can discern the relative criticality, the measure of concern, and the type and degree of remedial action needed to address the issue. When there is justification to take dam safety actions to reduce or better define risks, a suite of options should be identified, and the estimated costs and potential benefits of each option should be developed and presented.

The most obvious and direct factors that enter into the risk assessment are the results of a risk analysis. These results may come in the form of quantitative/numeric results or qualitative statements that indicate the measure of concern relative to public safety. Quantitative results provide three measures related to risk (incremental risk). They are (FEMA, 2015):

- Likelihood of occurrence of a failure or adverse consequence in terms of annual probability.
- Estimated 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 “average annual life loss”. This information is commonly portrayed on f-N and F-N charts.
- The economic damages (e.g., 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 average annual economic loss. This information is commonly tabulated and may be portrayed on F-\$ charts.

However, there are many factors that may be included in a dam safety case and can be considered in the decision. They include (FEMA, 2015):

- The risk analysis input for the dam safety case
- The design and construction of the dam, including defensive design features
- The past and future performance monitoring of the dam
- Environmental considerations
- Public perception and public input
- Regional, social, and economic considerations
- Ease, difficulty, and practicality of remediation
- Potential to do harm as a result of carrying out remediation
- Uncertainty about the results and the success of the remediation

This chapter focuses on a risk-informed approach to make dam safety decisions. This method has the advantage of providing a more consistent basis for decision making. Also, since it is risk-informed, rather than risk-based, it allows for other important factors (such as those listed above) to be considered in the decision, beyond a sole reliance on numerical risk estimates.

3.1.2 Definition

Risk assessment is the process of making a decision recommendation on whether existing risks are tolerable and present risk measures are adequate, and if not, whether alternative risk reduction measures are justified or will be implemented (ICOLD, 2005). As defined by the Federal Emergency Management Agency (FEMA), risk assessment is “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 to mitigate or accept the risk” (FEMA, 2015).

3.1.3 Principles

A number of principles apply to risk assessments (FEMA, 2015). These include:

- Remedial actions should do no harm.
- The goal of remedial dam safety actions is to reduce risk to tolerable levels, including ALARP considerations.
- Some remedial actions may have unintended consequences.
- In order to implement some remedial actions, construction risks may be excessive during certain phases of the work. A remedial action to address a specific potential failure mode can temporarily or permanently increase the probability of another potential failure mode.
- Decisions should be risk-informed, not risk-based.
- Decisions should be based on consideration of the results of a risk analysis as a key input, but other factors, such as the uncertainty and confidence in the risk estimates, should also be considered.
- Decisions should not be based solely on where risk estimates plot on an f-N or F-N chart.
- The decisions made should consider the risk estimates, including the uncertainty and confidence in the risk estimates, the likely outcomes if dam safety actions are completed, and other factors important to the dam owners mission and regulatory agency's guidelines.

Interim risk reduction measures (IRRMs) should be considered and implemented where needed. While the ultimate goal may be to reduce risks to tolerable levels at a given dam, IRRMs can achieve timely incremental risk reduction, often at a reasonable cost. IRRMs are discussed in Chapter 4 – Risk Management.

3.2 BACKGROUND ON TOLERABLE RISK GUIDELINES

3.2.1 Tolerable Risk Concepts

Inherent in the use of risk analysis and risk-informed guidelines and, specifically, in risk assessment, is the recognition and understanding of tolerable risk. Tolerable risk concepts are used in risk assessment to guide the process of evaluating and judging the significance of estimated risks obtained from a risk analysis (Munger, et al, 2009).

Tolerable risks are:

- Risks that society is willing to live with so as to secure certain benefits;
- Risks that society does not regard as negligible (broadly acceptable) or something it might ignore;
- Risks that society is confident are being properly managed by the owner; and
- Risks that the owner keeps under review and reduces still further if and as practicable (Adapted from HSE, 2001) (Bowles, 2007).

Each of these four conditions of tolerability has implications for dam safety. In a life safety context, the key point in this definition is that a level of risk society is willing to tolerate and is not defined by the dam owner but rather by society itself. The Federal Energy Regulatory Commission (FERC), as the regulatory authority, acts on behalf of society in its assessments of risks of jurisdictional dams.

Many factors contribute to society's risk tolerance, including:

- The perceived benefits received by the population at risk relative to the risk,
- The degree to which the risk is imposed on the people at risk as opposed to accepted by the population,
- Whether or not the person at risk can exert some level of control over the risk,
- Is the hazard common (well known to the population at risk),
- Does the hazard elicit a feeling of dread, and
- Other factors.

Various means have been utilized to try and determine how society as a whole views various risks. The two main methodologies are “revealed preference” and “expressed preferences”. The revealed preference methodology starts with an assumption that society has reached a balance between risk and benefits which can be revealed by using economic or life loss statistics from recent years to estimate society's risk tolerance. Expressed preferences are determined by using questionnaires to gauge the

public's risk tolerance. There are pros and cons of both methodologies.

As with any statistical analysis, the use of revealed preferences requires that the data set used to draw conclusions about the tolerability of a given risk must be similar to the subject of the analysis. This is a difficult task in trying to determine a tolerable level of life loss from dam failures in the United States as we have a very small data base of recent failures that have resulted in loss of life. Use of revealed preferences also must take into account that society's risk tolerance changes over time and that what may have been tolerable 40 years ago may not be tolerable today. Fischoff (2010) put a different perspective on using historical failure:

"Deriving standards from involuntary decisions means interpreting as acceptable whatever tradeoffs people have been forced to accept. It means enshrining the injustices of the past in prescriptions of the future."

Determining a tolerable risk level from either expressed preferences or revealed preferences is outside the common bounds of dam safety engineering and requires utilizing expertise from the social sciences.

A framework for understanding the tolerability of risk has been proposed by Health and Safety Executive (HSE) in the United Kingdom and is shown in Figure 3-1 (HSE, 2001). Fundamentally the triangle in Figure 3-1 represents increasing levels of risk for a particular hazard as one moves from the bottom of the triangle towards the top. The width of the triangle suggests the effort that must be expended in addressing the risks. In general, the triangle can be divided into three broad zones:

1. The zone at the top represents an unacceptable region. For practical purposes, a risk falling in this region is regarded as unacceptable, no matter what the benefit associated with the risk. Any activity or practice giving rise to risks falling in this region would, as a matter of principle, be ruled out unless the activity or practice can be modified to reduce the degree of risk so that it falls in one of the regions below, or there are exceptional reasons for the activity or practice to be retained.
2. The zone at the bottom represents a broadly acceptable region. "Risks falling into this region are generally regarded as insignificant and adequately controlled. The levels of risk characterising this region are comparable to those that people regard as insignificant or trivial in their daily lives. They are typical of the risk from activities that are inherently not very hazardous or from hazardous activities that can be, and are, readily controlled to produce very low risks" (HSE, 2001).
3. The zone between the unacceptable and broadly acceptable regions is the tolerable risk range. Other factors must be considered to determine if risks in this zone are truly considered to be tolerable.

The tolerable risk limit line (tolerable risk reference line) distinguishes the boundary between unacceptable risk and the range of tolerability.

Tolerability of Risk Framework for Dams

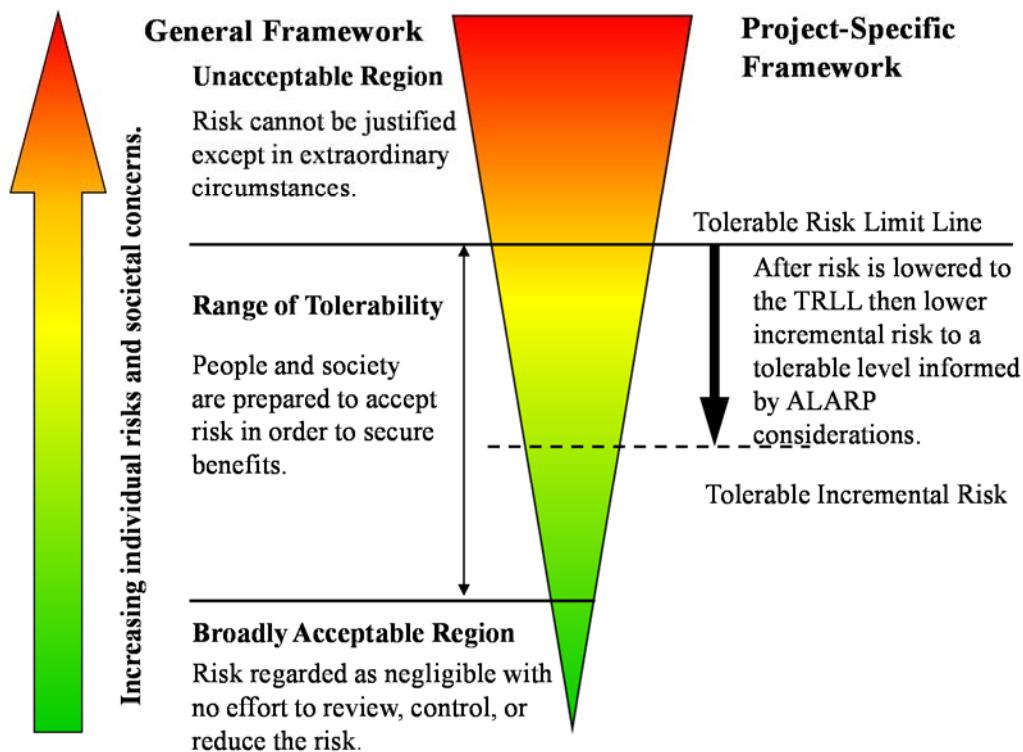


Figure 3-1. Generalized and Project Specific Tolerability of Risk Framework
(Adapted and Modified from HSE, 2001 and USACE, 2014)

Acceptable risks are risks, for the purposes of life or work, everyone who might be impacted is prepared to accept assuming no changes in risk control mechanisms. Such risk is regarded as insignificant and adequately controlled. Action to further reduce such risk is usually not required (USACE 2014).

Dams provide certain net benefits to society such as water supply, flood control, navigation, power, recreation, etc. Dams may also pose a risk to those who live downstream of a dam. Society does not necessarily view the risks as negligible, especially for high hazard potential dams, but society is willing to tolerate the risk to obtain those benefits (USACE, 2014). In addition, society expects that the risks are kept under review and reduced further if and as we can. Managing the risks associated with a dam is therefore not a one-time static endeavour but a continuous process of review and action.

3.2.2 Key Principles

Two fundamental principles, from which tolerable risk guidelines are derived, are described as follows in ICOLD (2005):

- Equity. The right of individuals and society to be protected, and the right that the interests of all are treated with fairness, with the goal of placing all members of society on an essentially equal footing in terms of levels of risk that they face.
- Efficiency. Efficiency is the need for society to distribute and use available resources so as to achieve the greatest benefit.

There can be, and often is, conflict in achieving equity and efficiency. Achieving equity justifies the establishment of maximum tolerable risk for individual and societal risk. Achieving efficiency justifies a limit to how much of society's resources (money, effort, etc.) is spent on reducing risks. Efficiency is defined by the risk level where marginal benefits equal or exceed the marginal cost. Equity requires that a tolerable risk should be met regardless of the lack of economic support or the magnitude of the cost (USACE, 2014). Equity implies the need for this even if efficiency does not support reducing risks to meet tolerable risk. There is, therefore, a need to obtain an appropriate balance between equity and efficiency in the development of tolerable risk guidelines. In general, society is more averse to risks if multiple fatalities were to occur from a single event and hence impact on society as a whole (HSE, 2001). In contrast, society tends to be less averse to risks that result from many individual events resulting in only one or two fatalities, even if the total loss from the sum of fatalities from all of the small loss accidents is larger than that from the single large loss accident. This leads to the notion that tolerable risk should consider both societal and individual risks as an integral part of the framework for managing risks.

The “as-low-as-reasonably-practicable” (ALARP) considerations provide a way to address efficiency aspects in both individual and societal tolerable risk guidelines. The ALARP considerations apply below the tolerable risk reference line of Figure 3-1. The application of ALARP considerations mean that actions should be taken to reduce risk below the tolerable risk reference line until such actions are impracticable or not cost effective. ALARP is an explicit consideration in many dam safety risk assessment guidelines.

Determining that ALARP is satisfied is ultimately a matter of judgment. In making a judgment on whether risks are ALARP, a number of factors should be taken into account, as discussed in Section 3.3.6.2.

3.2.3 Tolerable Risk Guidelines

Risk assessment, which includes the organization's decision makers, can lead to a variety of decisions such as:

- Additional information is needed to better define the risks (increase confidence, decrease uncertainty) and risks need to be re-evaluated using the new information before making subsequent dam safety decisions.
- Remediation for a project or dam will not be required, but monitoring of the concern will continue.
- A nonstructural alternative will be implemented.
- An alternative that addresses the major portion of the concern, but does not deal with all aspects, will be the course of action (FEMA, 2015).

Threshold values are typically established to help guide decisions on tolerable risk. These are commonly referred to as tolerable risk guidelines. Some agencies and organizations that have developed tolerable risk guidelines for dam safety include:

- Australian National Commission on Large Dams (ANCOLD)
- New South Wales (NSW), Dam Safety Committee (DSC)
- Canadian Dam Association (CDA)
- U.S. Army Corps of Engineers (USACE)

Tolerable risk guideline plots from these agencies are included in Appendix 3A. The tolerable risk guidelines within the dam safety community are generally very similar and are founded on the work of the HSE and ANCOLD.

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. When a judgment is made that risks are as low as reasonably practicable, this is often determined by comparing the effectiveness of reducing risk further (evaluated by considering the cost to further reduce risk and the amount of risk reduction achieved, and then comparing it to other risk reduction actions implemented). If the costs to achieve an additional level of risk reduction are disproportionate, the current risk may be as low as reasonably practicable.

There are many factors besides the numerical estimate of risk that can contribute to the decision that no further action is justified, including (FEMA, 2015):

- 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
- The chance of success of an action
- Time to perform the remediation
- Other considerations

The risk remaining after decisions are implemented, related to a specific dam safety 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.

It should also be recognized that regardless of what actions are taken or not taken, there will always be a certain level of residual risk (USACE, 2014). Therefore, rather than ignoring or supposing that the risk is zero, it is appropriate that tolerable risk levels for various aspects of the dam be discussed and identified.

3.3 RISK GUIDELINES

3.3.1 General

As listed in Section 2.2.2 of Chapter 2, four types of risk measures will be estimated and evaluated:

1. Life safety risk – which includes incremental and non-breach risk within the context of tolerable risk guidelines.
2. Annual probability of failure (APF).
3. Economic considerations – which includes incremental and non-breach consequences.
4. Environment and other non-monetary consequences - which includes incremental and non-breach consequences.

Risk guidelines for these risk measures are discussed in the sections below.

3.3.2 Life Safety

As described in Section 2.2.3, three types of incremental life safety risk guidelines will be used under the FERC-D2SI tolerable risk guidelines.

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

The incremental life safety risk is to be evaluated against all three life safety guidelines.

Non-breach life safety risks are also to be evaluated.

3.3.2.1 Individual Incremental Life Safety

The individual incremental life safety risk (IR) to the identifiable person or group by location, that is most at risk, should meet the following and as shown on Figure 3-2:

1. For $IR \geq 0.0001$ (1E-04) Per Year. IR in this range is unacceptable except in extraordinary circumstances. Risks should be reduced to the tolerable risk reference line (1E-04) regardless of cost considerations and then further until ALARP is satisfied, except in extraordinary circumstances. The justification to take action to reduce or better define the risk increases as the estimates become greater than 0.0001 per year. Extraordinary circumstances will be evaluated by the FERC on a case-by-case basis.
2. For $IR < 0.0001$ (1E-04) to $IR \geq 0.000001$ (1E-06) Per Year. IR in this range will be considered intolerable unless ALARP considerations are satisfied. IR in this range will be considered tolerable provided the other tolerable risk guidelines are met, to include all aspects of the risks listed in Section 3.3.1 and the ALARP considerations are met.
3. For $IR < 0.000001$ (1E-06) Per Year. IR in this range will be considered tolerable provided the other tolerable risk guidelines are met, to include all aspects of the risks listed in Section 3.3.1 and the ALARP considerations are considered to evaluate potential risk reduction opportunities to further reduce the IR. The justification to take action to reduce or better define the risk diminishes as the estimates become smaller than 0.000001 per year.

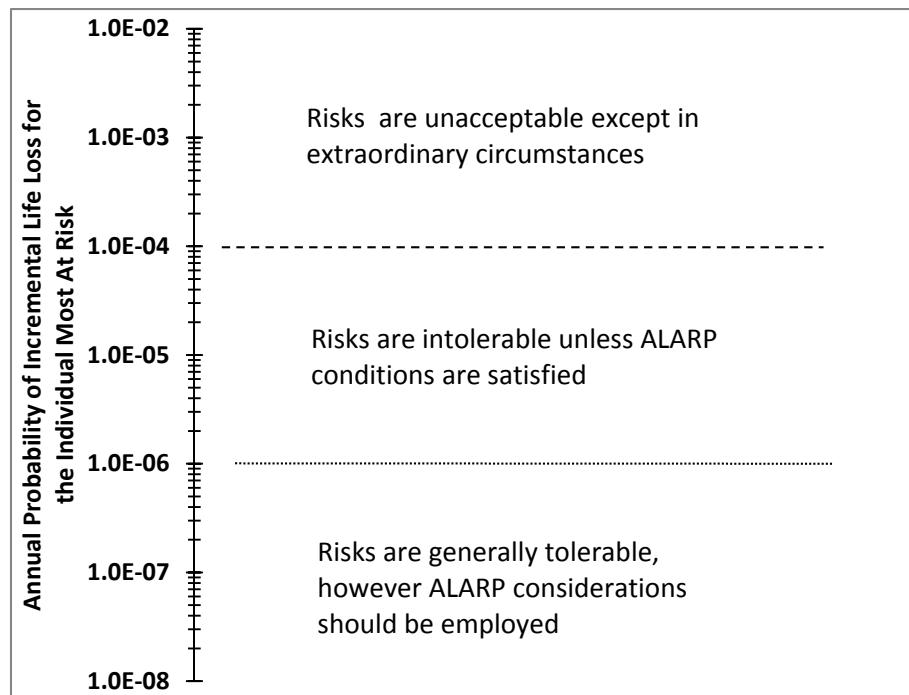


Figure 3-2. Individual Life Safety Risk Guideline for Incremental Risk

It is expected that for newly constructed dams, with the opportunity to make use of state of practice designs and technology, this will likely result in lower individual incremental risk when applying the ALARP principle.

The probability of individual life loss, which is used in the evaluation of individual incremental life safety risk, is not necessarily the same as the probability of failure that is used in the evaluation of the APF guideline, which is described in Section 3.3.3. The probability of life loss is based on the probability of failure and further takes into consideration the exposure factors to characterize the day-night, seasonal, warning, or other exposure scenarios, and the conditional probability of life loss given exposure to the dam failure flood. The level of detail that is appropriate for use in characterizing exposure factors should be “decision driven.”

3.3.2.2 Societal Incremental Life Safety

3.3.2.2.1 Probability Distribution of Potential Incremental Life Loss. The probability distribution of potential incremental risk will be evaluated based on the tolerable risk guideline shown on Figure 3-3.

Each of the four regions on the F-N chart (Figure 3-3) has the following attributes:

1. Societal Incremental Risk ≥ 0.001 (1E-03) Lives Per Year. Societal incremental risk above the tolerable risk reference line is unacceptable except in extraordinary circumstances. Risks should be reduced to below the tolerable risk reference line (1E-03) regardless of cost considerations and then further until ALARP is satisfied, except in extraordinary circumstances. The justification (urgency) to take action to reduce or better define the risk increases as the estimates become greater than 0.001 lives per year.
2. Societal Incremental Risk < 0.001 (1E-03) to Societal Incremental Risk ≥ 0.00001 (1E-05) Lives Per Year. Societal incremental risk in this range will be considered intolerable unless ALARP considerations are satisfied. Societal incremental risk in this range will be considered tolerable provided the other risks listed in Section 3.3.1 are considered tolerable, and the ALARP considerations are met. The justification (urgency) to take action to reduce or better define the risk diminishes as the risk estimates approach 0.00001 lives per year.
3. Societal Incremental Risk < 0.00001 (1E-05) Lives Per Year. Societal Incremental Risk in this range will be considered tolerable provided the other risks listed in Section 3.3.1 are considered tolerable, and the ALARP considerations are addressed to evaluate potential risk reduction opportunities to further reduce the incremental risk. The justification to take action to reduce or better define the risk diminishes as the risk estimates become smaller than 0.00001 lives per year.

4. Low Probability – High Consequence Area. If incremental life loss is estimated to equal or exceed 1,000 lives and the annual probability of potential life loss is less than 1 in 1,000,000 (1E-06) for an estimated life loss of in the range of 1000 or greater (low probability – high consequence area of Figure 3-3), the evaluation of the tolerability of risk must be based on a thorough review of the project benefits and risks as described below.

The qualifier “except in extraordinary circumstances” refers to a situation in which the government, acting on behalf of society, may determine that risks exceeding the tolerable risk may be tolerated based on special benefits that “the dam brings to society at large”. The justification for tolerating such high risks or high consequences is the wider interests of society. Risks, that would normally be unacceptable, can be tolerated on account of the special benefits, which the dam brings to society (ANCOLD, 2003). This is often the result of not having adequate feasible options to further reduce risks.

This is an example of the conflict between the fundamental principles of equity and efficiency. Specifically, the maximum risk level that satisfies equity considerations can be at the expense of reducing efficiency (USACE, 2014). The equity consideration might be relaxed because of special benefits that are deemed to outweigh the increased residual risk. This exception might be made where the incremental potential life loss and economic consequences are large, but where the probability of failure or breach is very low and state-of-the-practice risk management measures have been implemented. For dams in this area on Figure 3-3, the FERC will look critically at the confidence in the estimate of the incremental risk. Full compliance with essential FERC engineering guidelines will be expected. The adequacy of potential failure modes analysis and risk assessment will be carefully examined. The FERC would reach a decision based on the merits of the case.

For new dams or major modifications, the societal incremental risk should be less than the tolerable risk reference line shown on Figure 3-3, except in extraordinary circumstances. However, it is expected that new dams, with the opportunity to make use of state of practice designs and technology, will likely result in lower societal incremental risk being considered when applying the ALARP principle.

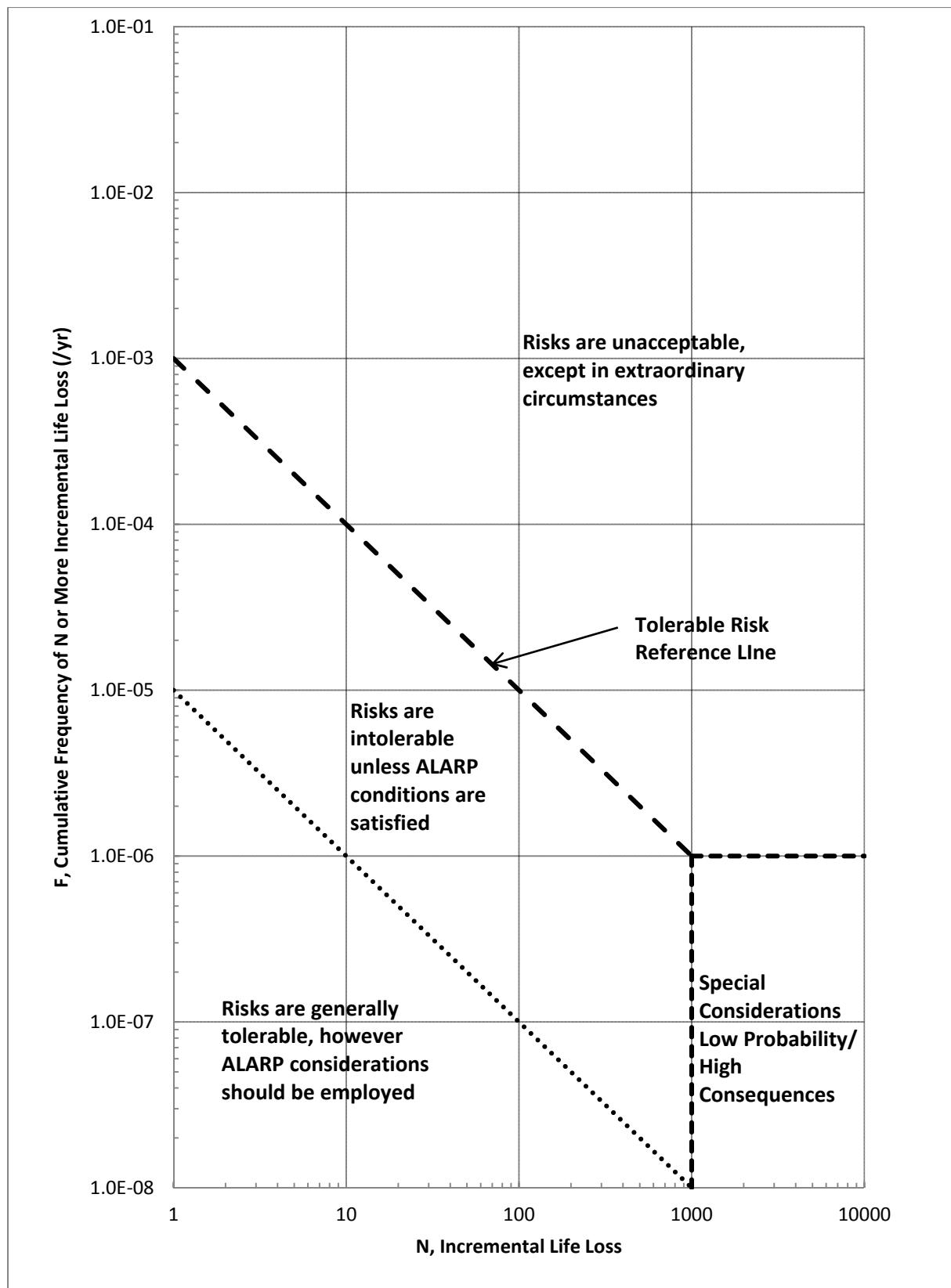


Figure 3-3. Societal Risk Guideline for Incremental Risk (F-N)

3.3.2.2.2 Average Annual Life Loss (AALL). The AALL associated with the incremental risk will be evaluated based on the tolerable risk guideline shown on Figure 3-4.

Each of the four regions on the f- \bar{N} chart (Figure 3-4) has the following attributes:

1. $AALL \geq 0.001$ (1E-03) Lives Per Year. AALL in this range is unacceptable except in extraordinary circumstances. Risks should be reduced to below the tolerable risk reference line (1E-03) regardless of cost considerations and then further until ALARP is satisfied, except in extraordinary circumstances. The justification (urgency) to take action to reduce or better define the risk increases as the estimates become greater than 0.001 lives per year.
2. $AALL < 0.001$ (1E-03) to $AALL \geq 0.00001$ (1E-05) Lives Per Year. AALL in this range will be considered intolerable unless ALARP considerations are satisfied. AALL in this range will be considered tolerable provided the other risks listed in Section 3.3.1 are considered tolerable, and the ALARP considerations are met. The justification (urgency) to take action to reduce or better define the risk diminishes as the risk estimates approach 0.00001 lives per year.
3. $AALL < 0.00001$ (1E-05) Lives Per Year. AALL in this range will be considered tolerable provided the other risks listed in Section 3.3.1 are considered tolerable, and the ALARP considerations are addressed to evaluate potential risk reduction opportunities to further reduce the AALL. The justification to take action to reduce or better define the risk diminishes as the risk estimates become smaller than 0.00001 lives per year.
4. Low Probability – High Consequence Area. If the incremental life loss is estimated to equal or exceed 1,000 lives and the frequency of dam failure is estimated to less than 1 in 1,000,000 (1E-06) per year, the evaluation of the tolerability of risk must be based on a thorough review of the project benefits and risks as described in Section 3.3.2.2.1.

For new dams or major modifications, the societal incremental risk should be less than the tolerable risk reference line (1E-03) shown on Figure 3-4, except in extraordinary circumstances. However, it is expected that new dams, with the opportunity to make use of state of practice designs and technology, will likely result in lower societal incremental risk being considered when applying the ALARP principle.

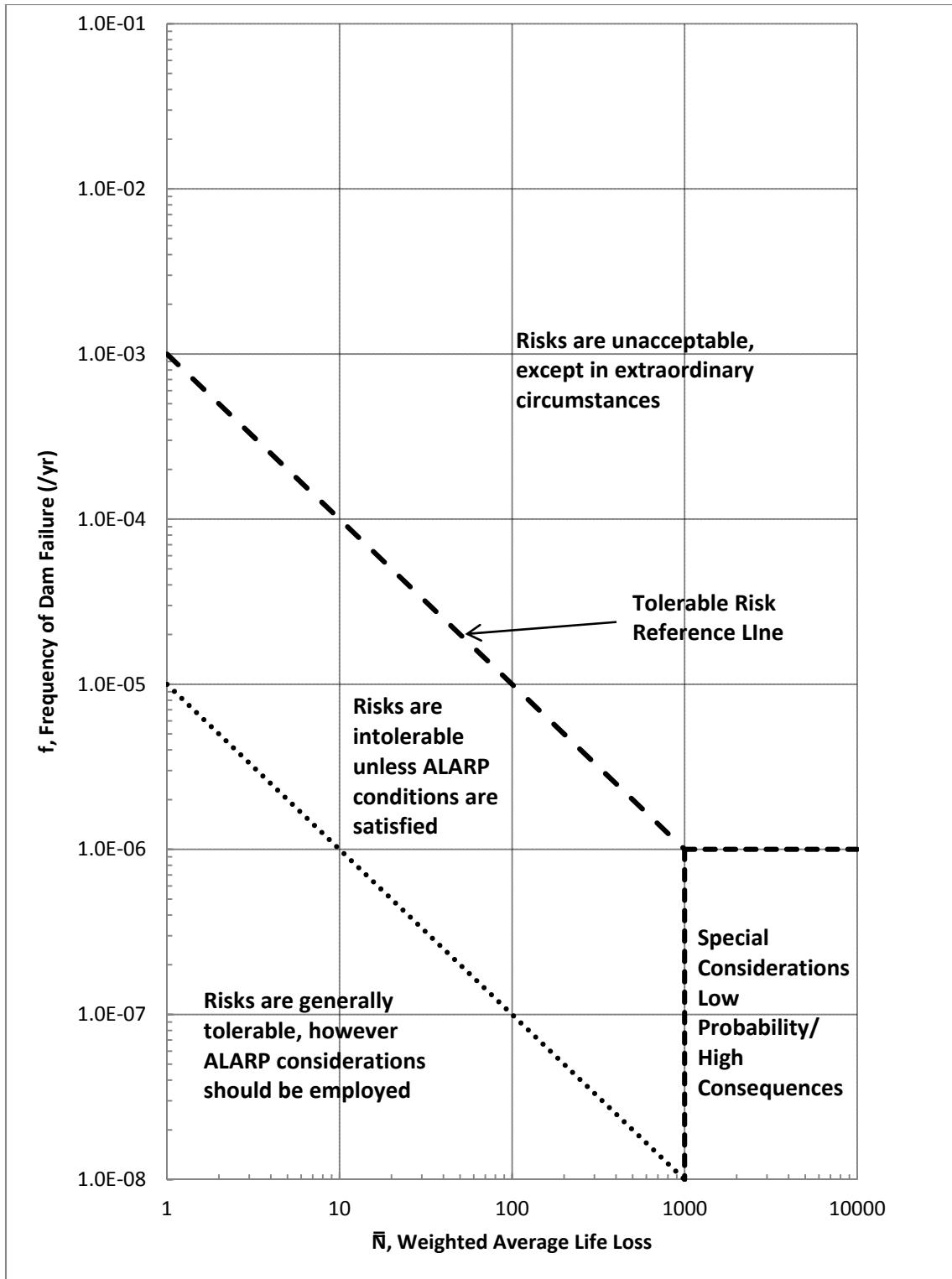


Figure 3-4. f - \bar{N} Chart for Displaying Average Annual Life Loss for Incremental Risk

3.3.2.3 Non-Breach Life Safety

The FERC has no explicit risk guideline for non-breach life safety risk.

The estimated non-breach life safety risk is to be plotted on the probability distribution of potential life loss (F-N) chart shown on Figure 3-5. The diagonal dashed line shown on this F-N plot **does not** have the same meaning as the tolerable risk reference line shown on Figure 3-3.

Figure 3-3 is for portraying and communicating the life safety risk associated with the incremental inundation risk in relation to the tolerable risk reference line. Figure 3-5 provides **a reference line** for communicating the estimated life safety inundation risk for the non-breach inundation scenario and allows comparison of the estimated non-breach life safety risk with the estimated incremental life safety risk.

Use of Figure 3-5 allows for comparing the estimated non-breach risk with the estimated incremental risk, after risk reduction and risk management measures have been implemented, thus framing and enabling the discussion that life safety inundation risk would continue to exist with a properly functioning dam. Plotting the non-breach risk on a similar plot as various risk reduction alternatives will make the discussion of non-breach risk more meaningful. Such plotting will make it obvious how each risk reduction alternative being considered is estimated to the non-breach risk, and perhaps suggest ways of improving the alternatives to lessen the likelihood of inadvertently increasing this non-breach risk and to improve management of the remaining non-breach risk.

Non-breach life safety risks include those scenarios where the dam operates as designed and intended, but due to high reservoir releases, loss of life may occur due to downstream inundation as a result of those releases. Understanding those conditions when and where loss of life may occur provides opportunities to develop risk reduction management plans or perhaps changes to operational releases and enhanced communication/warning systems with downstream agencies/populations.

Non-breach risk information can also be valuable to downstream communities to assist them in evaluating whether additional community flood risk studies may be warranted.

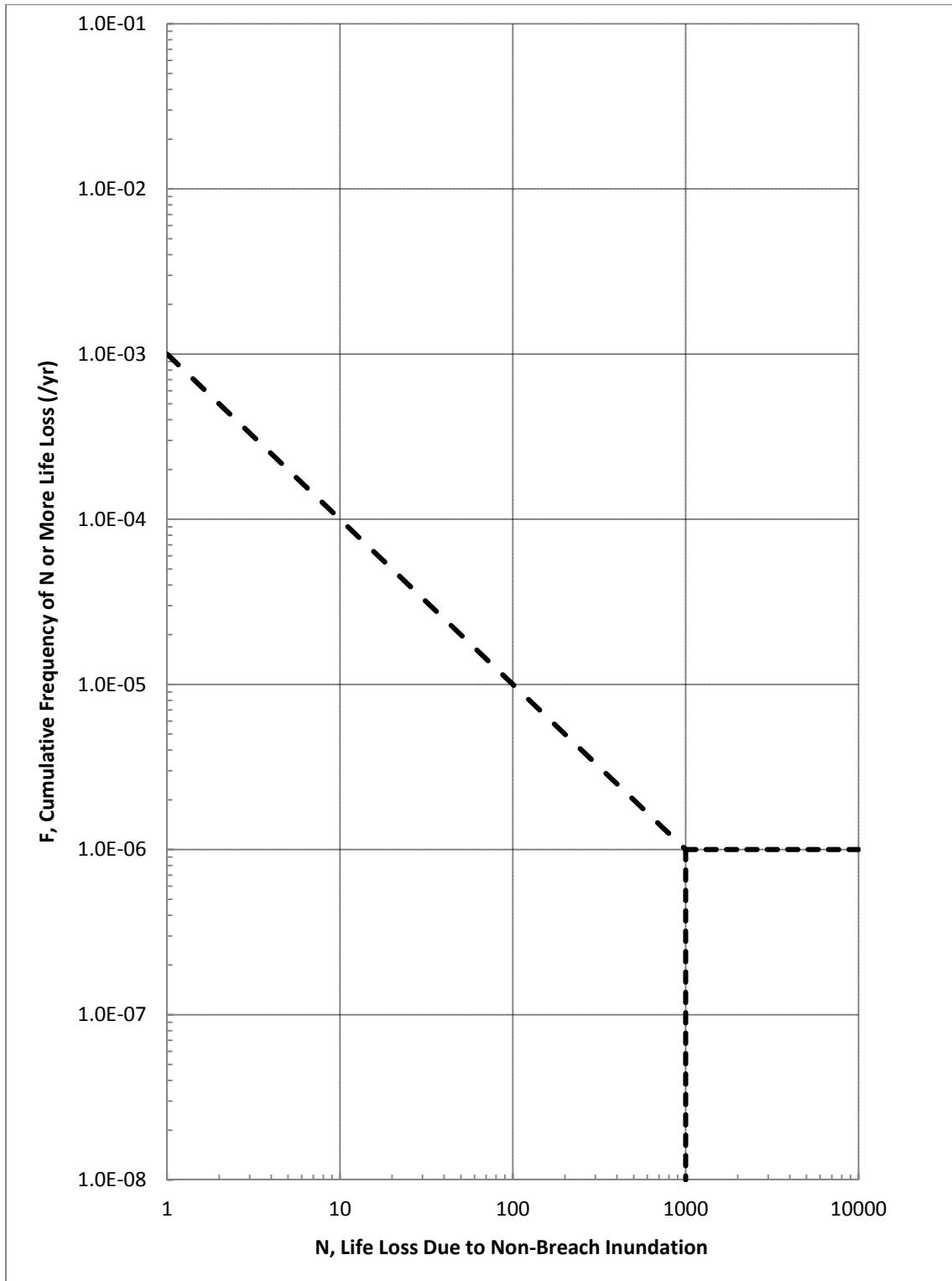


Figure 3-5. Chart for Plotting Non-breach Life Safety Risk

3.3.3 Annual Probability of Failure

The policy for the estimated APF under the FERC risk guidelines, based on the equity principle, is:

- APF ≥ 1 in 10,000 (1E-04) (0.0001) Per Year. Annual probability of failure in this range is unacceptable except in extraordinary circumstances. The justification to take action to reduce or better define risk increases as the risk estimates become greater than 1E-04 (0.0001) per year.
- APF < 1 in 10,000 (1E-04) (0.0001) Per Year. Annual probability of failure in this range will be considered tolerable provided the other risk guidelines are met, to include all aspects of risks listed in Section 3.3.1 and the ALARP considerations. The justification to take action to reduce or better define the risk diminishes as the risk estimates become smaller than 0.0001 (1E-04) per year.

3.3.4 Considerations

In addition to the tolerable risk guidelines for annual probability of failure (APF) and life safety, the ALARP considerations will be applied to determine how much below the tolerable risk reference line the life safety risk is to be reduced. All of these risk measures together will be considered when evaluating a dam and making risk management decisions; but life safety risk will be given preference, with economic consequences and environmental consequences being given due consideration. For those projects where there is very low or no life safety risk, economic consequences and annual probability of failure will be the primary considerations along with environmental consequences in making risk management decisions.

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

3.3.5.1 Background

The U.S. common law system has developed two principles that are pertinent to risk; strict liability and the concept of ALARP.

Strict liability grew out of an English case of *Fletcher vs. Rylands* involving the failure of a reservoir and the subsequent flooding of an adjacent mine. The court found (*Blackburn*, 1866):

*“... the true rule of law is, that the person who, for his own purposes, brings on his land and collects and keeps there anything likely to do mischief if it escapes, must keep it in at his peril, and if he does not do so, is *prima facie* answerable for all the damage which is the natural consequence of its escape.”*

The concept of strict liability has been adopted by most U.S. states.

The courts have also addressed the standard of care an individual or organization owes to the public to assure they are not subjected to intolerable risks. The ALARP principle is a means by which the courts may judge whether or not an owner has discharged his or her duty to protect the public.

The ANCOLD (2003) individual and societal risk guidelines include an important consideration that the risk is to be reduced to tolerable risk to an extent determined in accordance with the ALARP considerations. Determination is both qualitative and quantitative in nature.

Where reducing risk, ALARP is the test and a decision will be supported by knowledge of the risk, the "cost" (sacrifice) of risk reduction measures and the benefits of risk reduction. This requires knowledge of the change in harm averted, and where the measure does not achieve elimination, this is informed by assessment of the scenarios before and after the measure. The balance is biased in favor of risk reduction measures by "gross disproportion" (Bea, 2006).

The ALARP principle only has meaning in the context of evaluating proposed risk reduction options. It is not a consideration in the initial assessment as to whether or not the risk associated with a dam, in its existing state, is tolerable.

A simple analogy would be - would you spend one dollar to reduce the probability of life loss by a factor of a thousand? Most likely the answer is "Yes". On the other hand would you spend a billion dollars to reduce the probability of life loss by 0.0000001 percent? Most likely the answer is "No". In the first case the benefit (reduced probability of life loss) is clearly greater than the cost. In the second case the cost is most likely much greater (disproportionately so) than the benefit. Application of ALARP aims to balance costs and benefits as defined in the "concept of disproportionality".

Assessment as to whether or not proposed risk reduction measures meet the ALARP principle requires, among other factors, a means of assessing if the cost of implementing the proposed measures are grossly disproportionate to the improvement gained. In the United States this is often done by comparing the cost of the improvement to the value of a statistical life (VSL). VSL is a measure of the cost effectiveness of reducing life safety risk and is used in the United States by Federal agencies to justify regulatory rule making pursuant to Executive Order 12,866 (Viscusi and Gayer, 2002). The Federal Office of Information and Regulatory Affairs (OIRA) defines VSL as "individuals' willingness to pay (WTP) for reductions in risks of premature death."

There is no single agreed upon number for VSL among agencies in the United States. A 2003 circular from the Office of Management and Budget (OMB) suggested agencies use values between one and 10 million dollars (OMB, 2003). Many Federal agencies now

reference the annual work that the U.S. Department of Transportation (USDOT) publishes on the subject. The USDOT, in a 2014 memo “Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses”, identified \$9.2 million as the value of a statistical life using a base year of 2013 (USDOT, 2014).

3.3.5.2 ALARP Determination

In making a judgment on whether incremental risks are ALARP, the following factors must be taken into account: the level of incremental risk in relation to the tolerable risk reference line; the cost-effectiveness of the risk reduction measures; the disproportionality of the investment to the benefits associated with a prevented fatality; good practice; societal concerns as revealed by consultation with the community and other stakeholders; and other factors. The specific ALARP considerations to be used are listed below:

1. The cost-effectiveness of the incremental risk reduction measures. Cost-effectiveness of the risk reduction measures and the alternative plans will be used to guide the selection of the measures and plan to be implemented. Reducing the incremental life loss risk to the tolerable risk reference line and below is to be done in a cost effective manner. The adjusted "cost-to-save-a-statistical-life" (aCSSL) is used to evaluate this measure.

Chapter 2 - Risk Analysis describes the methodology to compute aCSSL.

There is no value of a aCSSL that indicates a threshold for which it can be said that ALARP is satisfied. Instead, the confidence and degree of defensibility with which one can conclude that ALARP has been met increases as the aCSSL increases. In using aCSSL to evaluate competing risk reduction alternatives, the smaller values of aCSSL indicate that a risk reduction alternative is “better value for the money”.

2. The level of incremental risk in relation to the tolerable risk reference line. When the estimated life safety incremental risk has been reduced to the tolerable risk reference line, the ALARP consideration leads to the question, "How far below that reference line is the level of risk to be reduced?"

In evaluating this ALARP factor, the further below the tolerable risk reference line the weaker the rational for further risk reduction efforts.

3. Disproportionality. A disproportionality factor has been used by some agencies (HSE) and organizations (ANCOLD) as a test to assess whether a dam safety

investment is grossly disproportionate to the benefits associated with a prevented fatality.

HSE developed a sliding scale of ‘proportion factor’ that varies with the level of risk. This scale is based on the principles of:

- a. The greater the risk, the less weight will be given to the factor of cost
- b. The greater the risk, the higher the proportion may be before being considered gross disproportion, but the disproportion must be gross.

The ANCOLD (2003) guidelines are based on HSE, which indicates as generally reasonable, a disproportionality factor of 10 for risks just below the limit of tolerability (tolerable risk reference line) and dropping to approximately 3 for risks just above the broadly acceptable level (two orders of magnitude below the limit of tolerability). It’s worth noting here again that the FERC does not define a broadly acceptable level as does ANCOLD. The ANCOLD approach is shown in Tables 3-1 and 3-2 that shows the disproportionality ratio of the CSSL to the WTP. The disproportionality ratios in Tables 3-1 and 3-2¹ have been adjusted from the ANCOLD CSSL values using a VSL of approximately \$10M/statistical fatality prevented.

Table 3-1. ANCOLD Guidance on ALARP Justification for Risks just below the Tolerable Risk Limit (adapted from ANCOLD, 2003)

ALARP Justification Rating	Range of Disproportionality Ratios	
	Greater than or equal to	Less than
Very Strong	Zero	0.5
Strong	1	2
Moderate	2	10
Poor	10	

Table 3-2. ANCOLD Guidance on ALARP Justification for Risks just above the Broadly Acceptable Region (adapted from ANCOLD, 2003)

ALARP Justification Rating	Range of Disproportionality Ratios	
	Greater than or equal to	Less than
Very Strong	Zero	0.2
Strong	0.3	1

¹ Tables 3-1 and 3-2 refer to the tolerable risk limit and broadly acceptable region, respectively. Based on their original use by HSE, the tolerable risk limit for individual risk may be considered to be 1 in 10,000 per year and the broadly acceptable limit may be considered to be 1 in 1,000,000 per year. However, the concepts of broadly acceptable risk and the limit of tolerability do not apply to dams as discussed elsewhere in these guidelines.

Moderate	1	3
Poor	3	

The FERC has no requirement for disproportionality. However, the FERC strongly recommends that a disproportionality ratio should be calculated for each risk reduction alternative. The dam owner should use their judgment and consult legal advice, as appropriate, to determine the appropriate disproportionality for each risk reduction alternative. The justification and evidence used to support the disproportionality selected by the dam owner for each risk reduction alternative should be well documented.

4. Good Practice. Good practice includes compliance with the *FERC Engineering Guidelines* and the Owners Dam Safety Plan. The *FERC Engineering Guidelines* are the state-of-the-practice for design, construction, operation, and maintenance of FERC-regulated dams as documented in current FERC or applicable industry related publications.

The FERC has adopted the following position (modified after NSW (2010)):

- a. Full compliance with the *FERC Engineering Guidelines* or good practice of an industry-recognized standard or good practice (where the FERC has no guidance or position) will normally be accepted by FERC as a demonstration of adequate safety in the long-term (not a temporary or short duration condition), provided the standard or good practice was intended to assure safety in the long-term, and
 - b. The FERC will generally accept risks higher than those achieved by the standards or good practice, described in the paragraph above, as adequately safe in the long-term provided the owner can reliably demonstrate that all risks comply with the tolerable risk guidelines, as defined herein, for safety in the long-term.
5. Societal concerns are revealed by consultation with the community and other stakeholders. Societal concerns in terms of community expectations are to be identified, documented, and resolved through public meetings, comment solicitation and response, or by other appropriate measures.

There is a lack of guidance and precedent for incorporating societal concerns for dam failure risks.

Societal concerns which should be factored into the assessment of ALARP include (modified from Victoria, 2012):

- Dams with high to very high consequences (e.g., an identified potential failure mode leading to a potential loss of life of more than 100);
- A highly vulnerable population at risk (such as a pre-school, nursing home, prison, etc. immediately downstream of a dam);
- Known and strong interdependence of a dam with critical infrastructure and the provision of essential services (power, water, etc.); and
- Situations where there is a lack of trust from the community that the risk is being adequately managed, perhaps resulting from an earlier dam safety incident or other significant loss experienced by the community.

An owner seeking to demonstrate that risks are ALARP is to identify and appropriately evaluate and address societal concerns and is to document the basis for the evaluation. The focus should be about what the societal concerns are and how they are addressed or mitigated. Reduction of risks may or may not be part of the mitigation. Conversely, reducing risks may, in part or in whole, address the societal concerns. In general, the following guidance should be considered:

- If societal concerns are low, the risks may be tolerable for a risk within the region of tolerability close to the tolerable risk reference line, provided that the other ALARP considerations and other factors so indicate.
 - If societal concerns are high, risks would normally need to be reduced to well below the tolerable risk reference line (at least two orders of magnitude below the tolerable risk reference line).
 - For intermediate societal concerns, intermediate levels could indicate risks are tolerable.
6. There are several other factors that can assist in the assessment of ALARP. These include (from Victoria, 2012):
- Duration that the risk applies – a greater focus on risk reduction may be prudent for potential failure modes associated with enduring risks compared to shorter term risks, although ANCOLD stresses that this is not necessarily the case. Short duration of risk here is not to be confused with rare events or low failure probability. In principle though, risk is expressed as an intensity (that is, as likelihood of consequences per annum) and intensity is not affected by duration.

- Availability of risk reduction options – in some situations, for some potential failure modes, it may not be possible to identify additional viable risk reduction options, thus justifying an ALARP determination. Owners will need to be mindful of technological and other developments and review this assessment periodically.
- Creation of new risks – risk reduction can itself be risky. In some cases reducing dam safety risks cannot be done without creating new and poorly understood risks. In such a situation, evaluation of ALARP may conclude that it is better to leave things as they are.
- Adequacy of the Potential Failure Modes Analysis – the determination of ALARP should be based on no less than a contemporary, thorough, and expert assessment of potential failure modes. Owners will need to remain informed of any changes to the body of knowledge regarding potential failure modes, which may result in new potential failure modes being considered or modifications to event trees associated with existing potential failure modes.
- Consideration of standards based approaches – satisfaction of contemporary engineering standards may assist with justifying an ALARP determination. Having met standards, there may be additional simple, low-cost risk reduction measures that could also be considered by dam owners and managers to further reduce risk.
- Benchmarking – Very little information is available in the US on benchmarking dam safety risks among dam owners. However, where benchmarking information may be available, in the form of precedents set forth by other dam owners in the available literature, this information could provide helpful information about investment and rate of risk reduction, particularly as risk diminishes over time with increasing investment, and this feedback information could help inform owner investment decisions.

Owners should consider these additional factors, and other factors that may be important in building a case for ALARP.

The evidence provided from the six categories of factors listed above will be used to evaluate ALARP. All else being equal, the first three factors (cost effectiveness, level of risk, and disproportionality) will be weighed more heavily in the ALARP determination. As such, it is incumbent on the dam owner to make sure the documentation and evidence to support the ALARP factors is clearly presented in the risk report and the case is clearly made in the report as to whether ALARP considerations for each potential failure mode

are met or not. The use of these factors will be used to inform and not to prescribe the outcomes of an ALARP evaluation.

Some final ALARP remarks:

- Affordability (the capacity of the dam owner to fund improvements) is not a consideration in judging whether risks are ALARP. The FERC will not consider the owner's financial circumstances other than by some possible concessions in the timing of the improvements.
- The FERC will review the information submitted in support of ALARP and review each case based on the merits and will advise the dam owner if the risks are or are not considered tolerable. However, it is important to note that although FERC may concur that a risk is considered tolerable, that rendering does not provide a legal decision or imply legal protection of the dam owner.

3.3.6 Economic Considerations

Economic considerations to help inform risk management decisions should include both the direct losses of the failure of a dam and other economic impacts on the regional or national economy.

The FERC has no tolerable risk guideline for economic consequences. In assessing economic consequences due to failure of the dam, it is important to evaluate not only the overall numeric value of the monetary consequence, but also those economic consequences that could have significant adverse impacts on the regional and national economy.

The FERC will review the information submitted in support of the economic analysis and review each case based on the merits. This information will be used by the FERC, in conjunction with the assessment of life safety risks and the consequences from other factors such as environmental and other non-monetary consequences, in the overall assessment of the tolerability of project risks.

3.3.7 Environmental Consequences

A dam failure and loss of the reservoir can impact a number of local, regional, and national non-monetary consequences including, environmental, cultural, and historic resources. Environmental risk is often viewed in terms of the uniqueness of habitat or cultural or other resources that may be destroyed or damaged and the potential for restoring them. Evaluating and quantifying these consequences can be difficult. Assessing the risks associated with these consequences can be even more difficult.

The FERC has no tolerable risk guidelines for these types of risks. In assessing these risks, the FERC will consider the information, analysis, and evidence presented, and will consider the following:

- Significance and magnitude of the consequence and cost and ease of implementation of risk reduction measures
- Effectiveness of risk reduction measures
- Magnitude of risk reduction achievable
- Precedents and other projects where action has been taken or not taken for similar type and magnitude of consequences
- Presence of other intolerable risks

This information will be used by the FERC, in conjunction with the assessment of life safety risks and the consequences from economic considerations, in the overall assessment of the tolerability of project risks.

3.4 DECISION MAKING

The concept and practice of the use of risk to inform dam safety 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 (FEMA, 2015). When dam safety became prominent in the late 1970s, decisions were primarily based on the standard hazard potential classification of the dam (e.g., high, significant, or low). Thus, a dam with an estimated potential life loss of more than one person in the event of dam failure was classified and treated in the same way as a dam with a potential life loss of several thousand people. This lack of discrimination between the levels of consequences among high hazard potential dams led to proposals of criteria that would take the magnitude of loss into consideration.

3.4.1 Dam Safety Case

It has been widely recognized that procedures and data available for dam safety risk analysis, while mostly quantitative, do not provide precise numerical results. Therefore, relying solely on the numeric estimates in comparison to hard line criteria (sometimes referred to as “risk-based” evaluation) would not be appropriate (BOR, 2011). The assessment of risks and the corresponding decisions are generally more complex than can be portrayed using only the numerical results of a risk analysis. The FERC and other federal dam safety agencies using risk-informed approaches have chosen to use a more “risk-informed” approach where additional information is included to support the assessment and case for proposed actions (or non-action). The intent in the assessment process is to use the entirety of the information available to build and support the case to take a particular action (or to take no action).

Though many concentrated efforts are made during a quantitative risk analysis to achieve high quality, defensible results, the risk estimates themselves are little more than index values. If arrived at in a consistent manner, they are useful in program management as they allow comparisons and rankings between different facilities, and promote a general sense of where the risks lie relative to the risk assessment guidelines (BOR, 2011). **It cannot be emphasized enough - these risk guidelines are not intended to be used as rigid decision-making criteria to declare a facility “safe” or “unsafe” based solely on a risk estimate.** Since the numbers are only approximate measures of risk, and since the risk guidelines themselves are not rigid, additional reasoning is essential to justify the risk estimates and the recommended actions. The case is intended to present rationale in a formal and methodical manner to persuade decision-makers to take responsible action (or to justify no action).

The case is a logical set of arguments used to advocate either the position that additional safety-related action is justified, or that no additional safety-related action is justified at

any given (current) time (BOR, 2011). The arguments string together key evidence regarding the three basic risk components (i.e. load probability, response probability, and consequences) so as to convince decision-makers that the dam's existing condition and ability to withstand future loading, the risk estimates, and the recommended actions are all coherent. Since uncertainty is inherent in each claim, the arguments should also address whether confidence is high enough for the conclusions to stand on the basis of existing evidence.

The safety case and the identification of risk reduction alternatives are recognized as essential elements in the assessment of tolerable risks. They represent understanding of existing conditions and predicted future behavior stated as objectively as possible. The risk estimates and the case to support them do not in themselves ensure the safety of a facility (BOR, 2011). The case becomes the basis and foundation for risk management. The understanding given to all, from the facility operators, to the owner's engineering and management staff, to the owner's consultants, to the FERC, by a well-constructed supporting case is intended to focus attention on behavioral and technical aspects essential to the facility's integrity so that the facility can be operated and maintained in as safe a manner as possible with the available information.

The case should be clearly presented so that all descriptions and terms are easy to understand by the prime audience, all arguments are cogent and coherently developed, all references are easily accessible, and all conclusions are fully supported and follow logically from the arguments (BOR, 2011).

3.4.2 Uncertainty, Confidence, and Sensitivity in Decision Making

3.4.2.1 Uncertainty

The quantification of risk estimates is dependent on available data and analyses regarding the design, construction, performance, and current condition of a dam (BOR, 2011). It also depends on the identified loads that the dam could be subjected to over its operating life and knowledge about how the downstream population would be affected by a dam breach flood. It is acknowledged that the quantification of risk estimates includes a degree of subjectivity regardless of how the estimates are made, and is a function of group dynamics, the experience and associated judgment of group members, models used in the analyses, and the available information for a dam (BOR, 2011). Thus, uncertainty in the risk estimates is expected. This uncertainty is typically captured by assigning ranges to probability and consequences estimates.

The role or contribution of uncertainty in proposed dam safety actions should be included in the dam safety case. It is not used explicitly in evaluating risks relative to the risk assessment guidelines. However, in prioritizing actions it is useful to consider how much of and how far the range in risk estimates lie above or below the tolerable risk guidelines

to better understand risks. It is also helpful to examine the “tightness” in the range of risk estimates (BOR, 2011). For example, if the mean and median of the risk estimates are significantly far apart, it could be an indication that there is significant skew in the risk estimates and that the high end of the estimates are driving the mean risk estimate. It would be important to understand these effects in the prioritization process.

3.4.2.2 Confidence

The “confidence” in the risk estimates and dam safety case is an important factor in prioritizing actions. As confidence increases in the risk estimates, actions (if necessary) should concentrate more on reducing the risk than reducing the uncertainties.

3.4.2.3 Sensitivity

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

Sensitivity studies can be used to assist in defining ranges of uncertainty of risk estimates (BOR, 2011). In addition, results from sensitivity studies can be used to judge the relative “confidence” in risk estimates and/or resulting conclusions. For example, if parametric studies indicate a relatively minor difference in estimated risks that leads to no change in whether the risks are tolerable or not tolerable, there would be confidence in the risk estimates relative to the decision. Conversely, if varying the parameter over a reasonable range results in a significant change in potential risks or conclusions, there would be less confidence.

3.4.2.4 Influence on Decision Making

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 to which the dam could be subjected to over its operating life. Additional uncertainty is introduced due to limited data and knowledge in the life loss, economic, and environmental consequences. When making a decision regarding future actions, the FERC will consider the risk estimates, the issues most influencing the risks, the sensitivity of the risks to particular inputs, ALARP considerations, 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 (BOR, 2011). Sensitivity studies are often useful in evaluating key parameters that additional information would address. These studies could be used to address the following questions:

- If the additional information was collected, what would be the possible range of outcomes?
- How might the risk change over that potential range?
- Could the confidence in the risk estimates increase?

Uncertainty should also be considered in evaluating the performance of risk reduction measures. Each measure will likely not have the same surety in achieving the intended risk reduction.

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, the FERC will 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 will be used to assess the need for future actions as well as an aid in setting the priority and urgency for initiating the actions.

3.5 REFERENCES

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APPENDIX 3A

TOLERABLE RISK GUIDELINES FROM OTHER AGENCIES AND ORGANIZATIONS

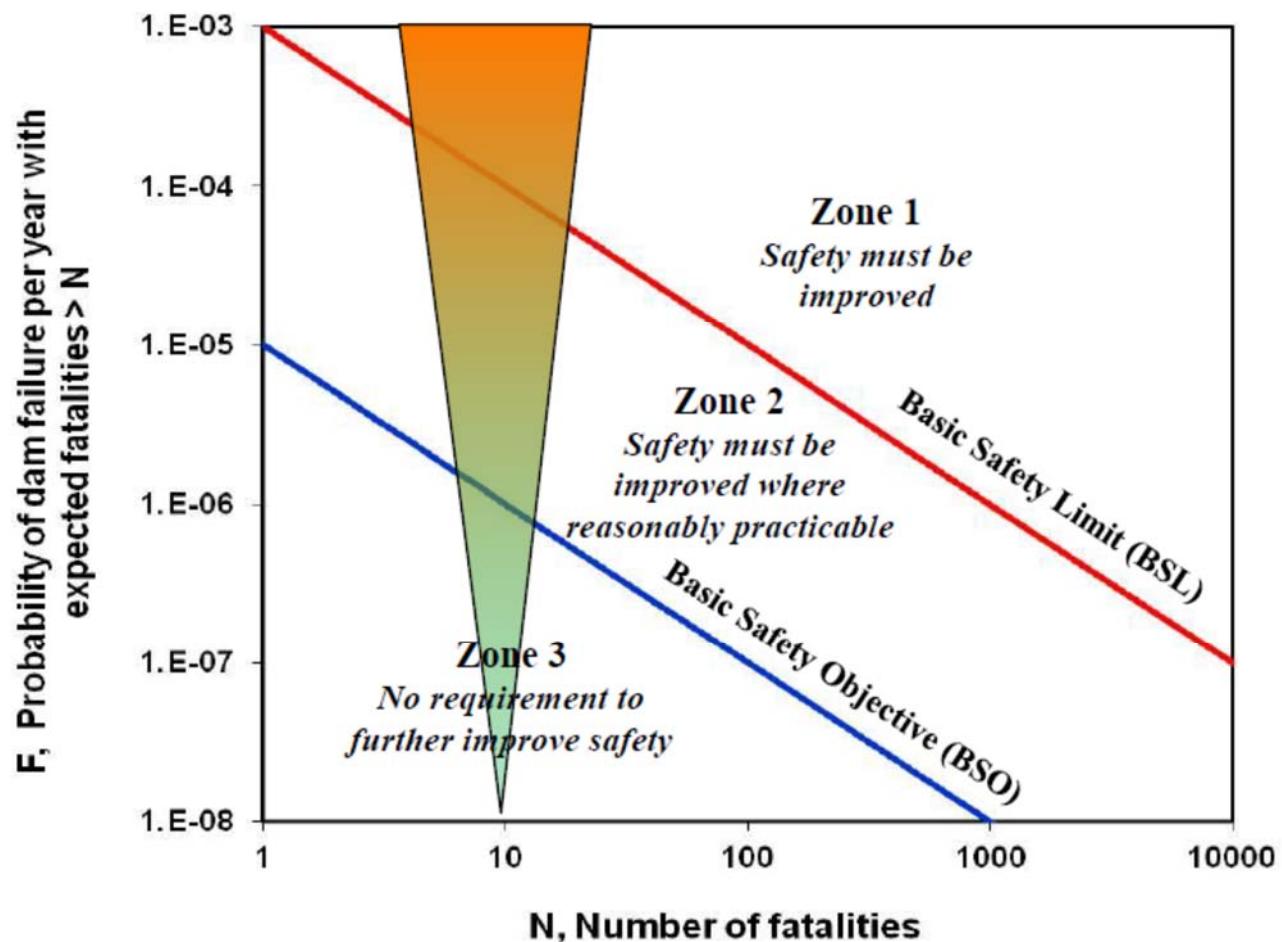


Figure 3A-1. Canadian Dam Association (2013) Risk Guidelines

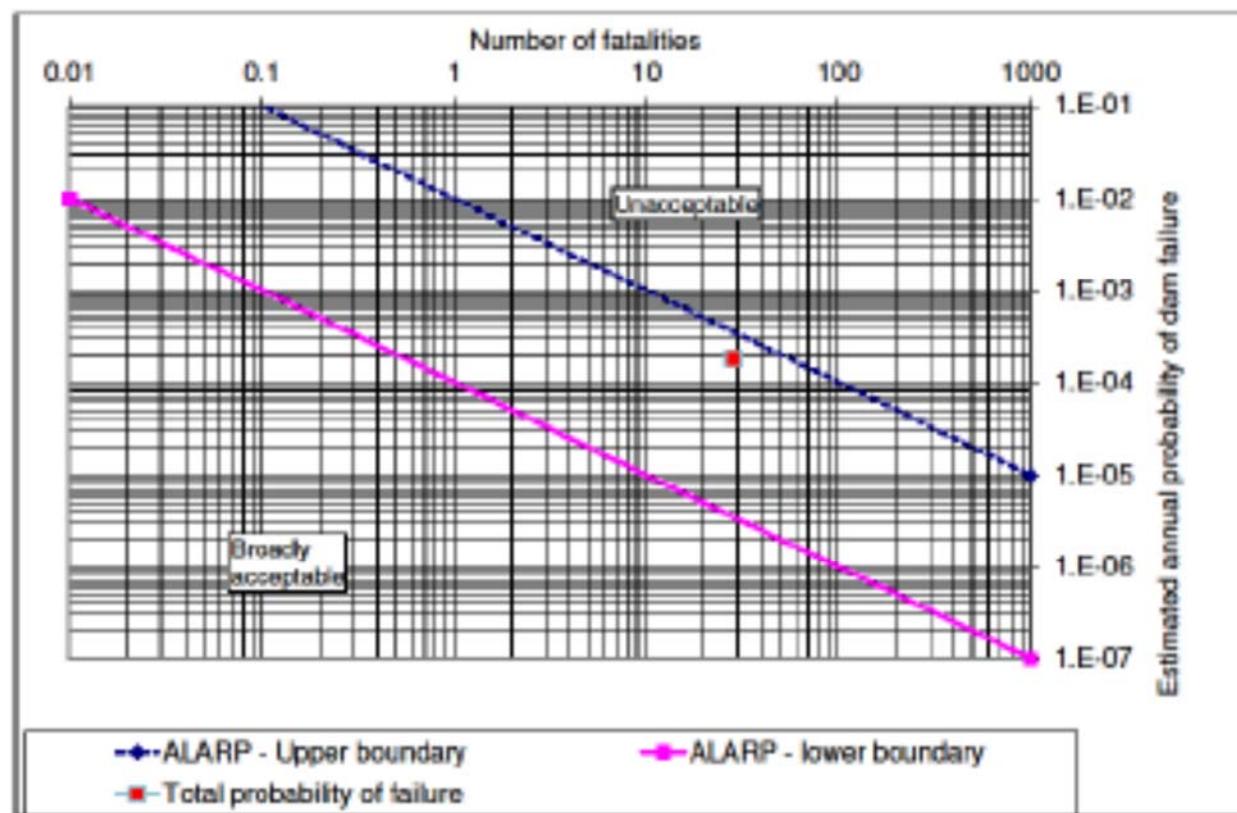


Figure 3A-2. United Kingdom Environment Agency (2013) Risk Guidelines, adapted from HSE

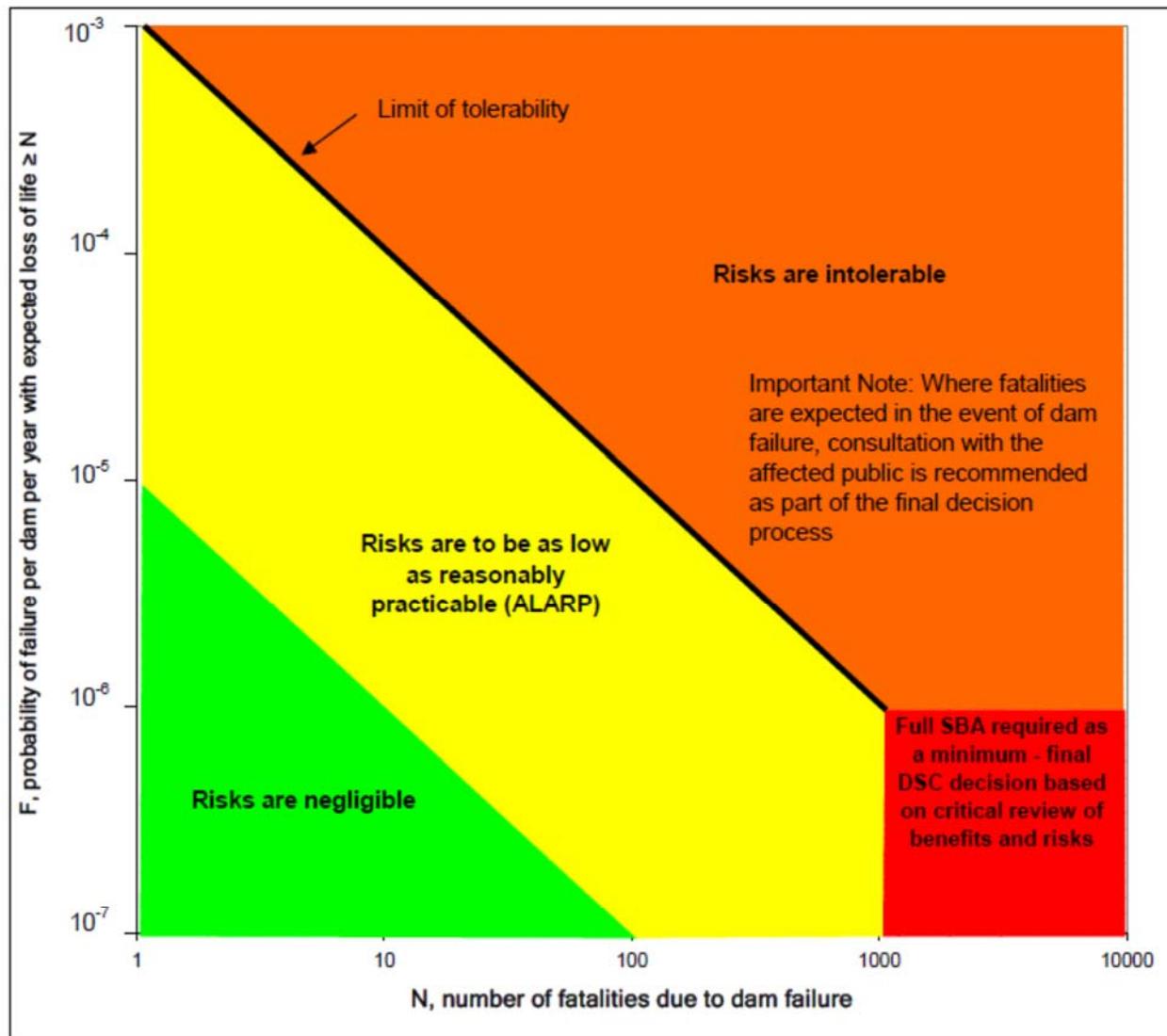


Figure 3A-3. New South Wales Dam Safety Committee (2006) Risk Guidelines

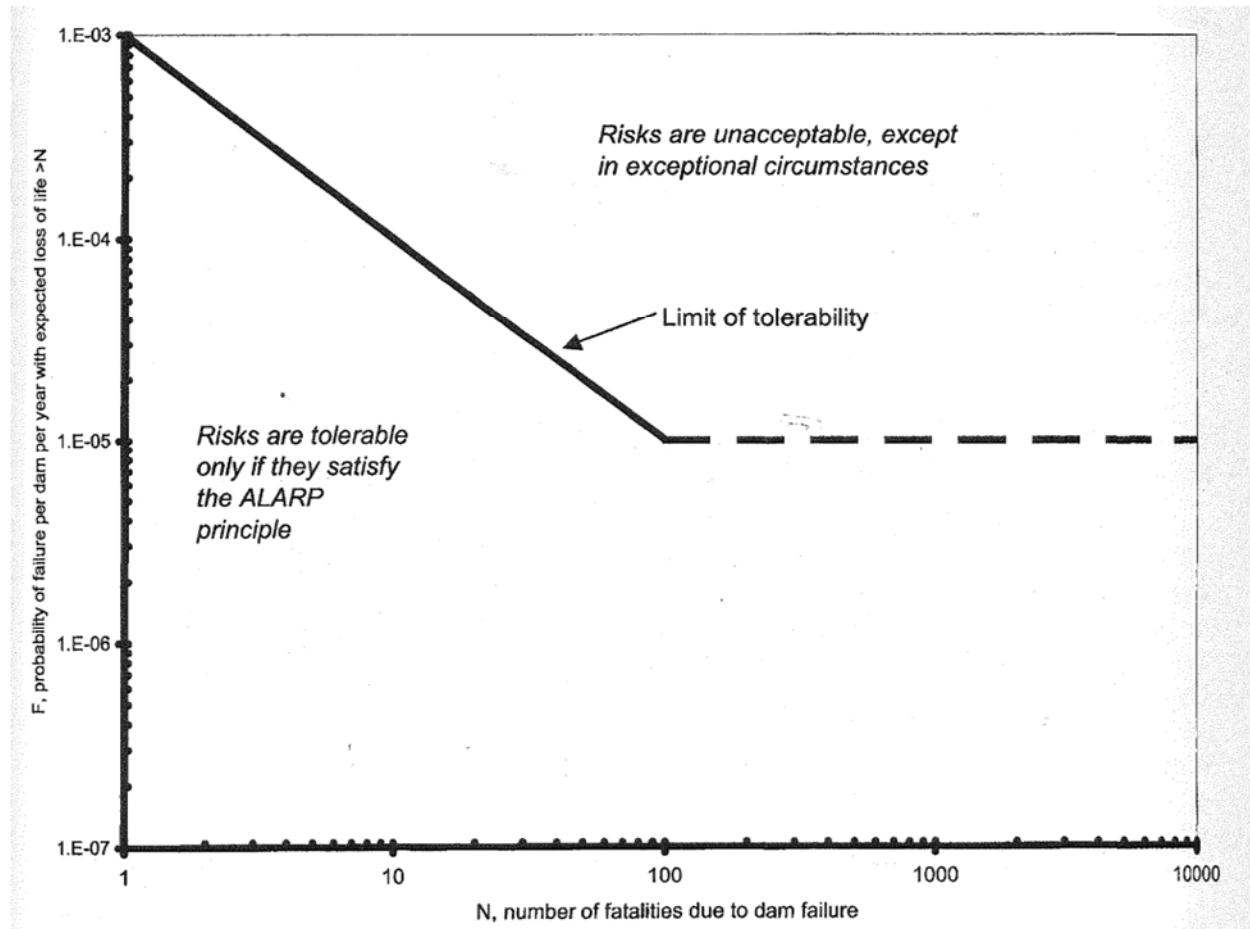


Figure 3A-4. Australian National Committee on Large Dams (2003) Revised Societal Risk Guidelines for Existing Dams

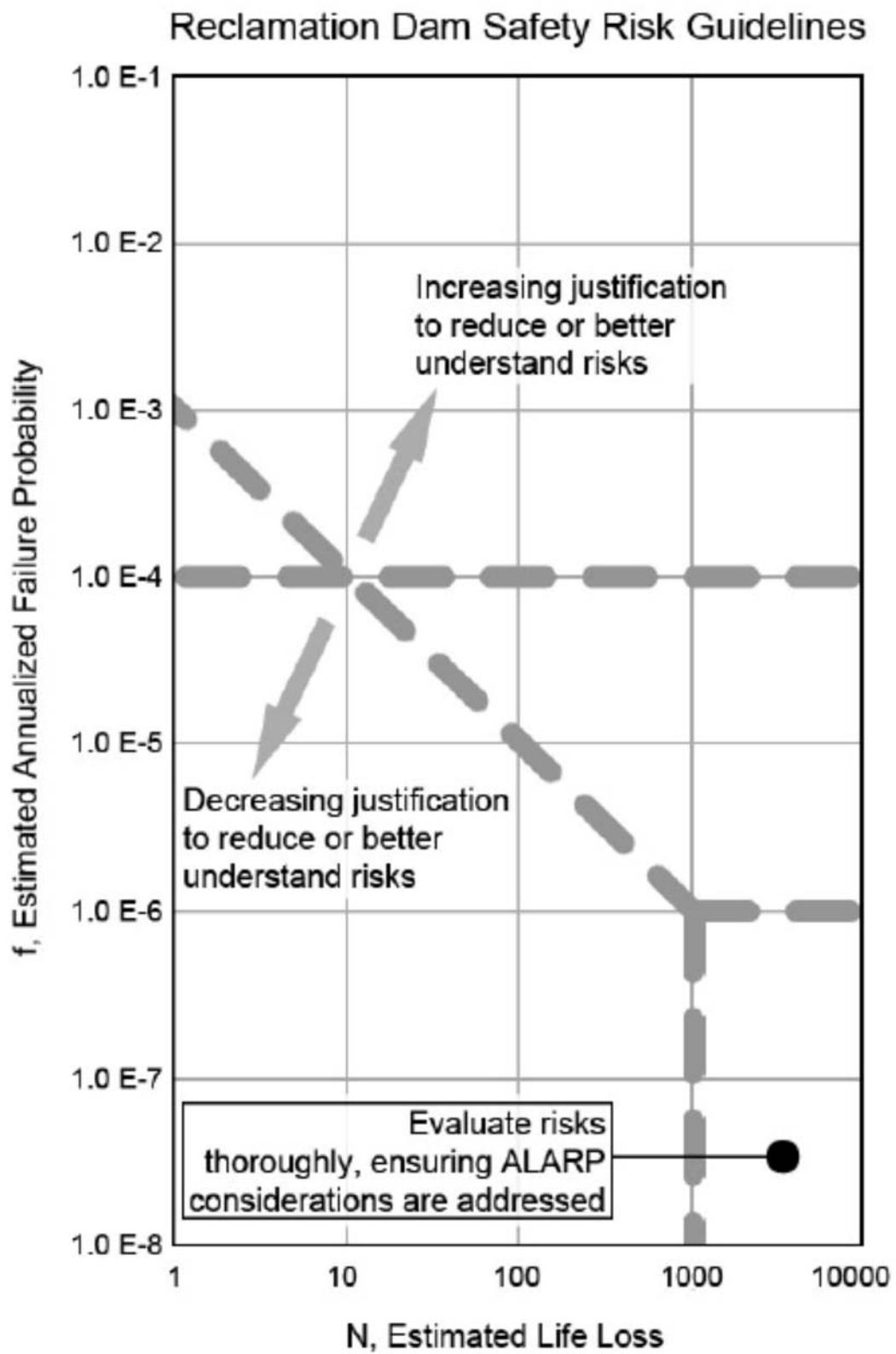
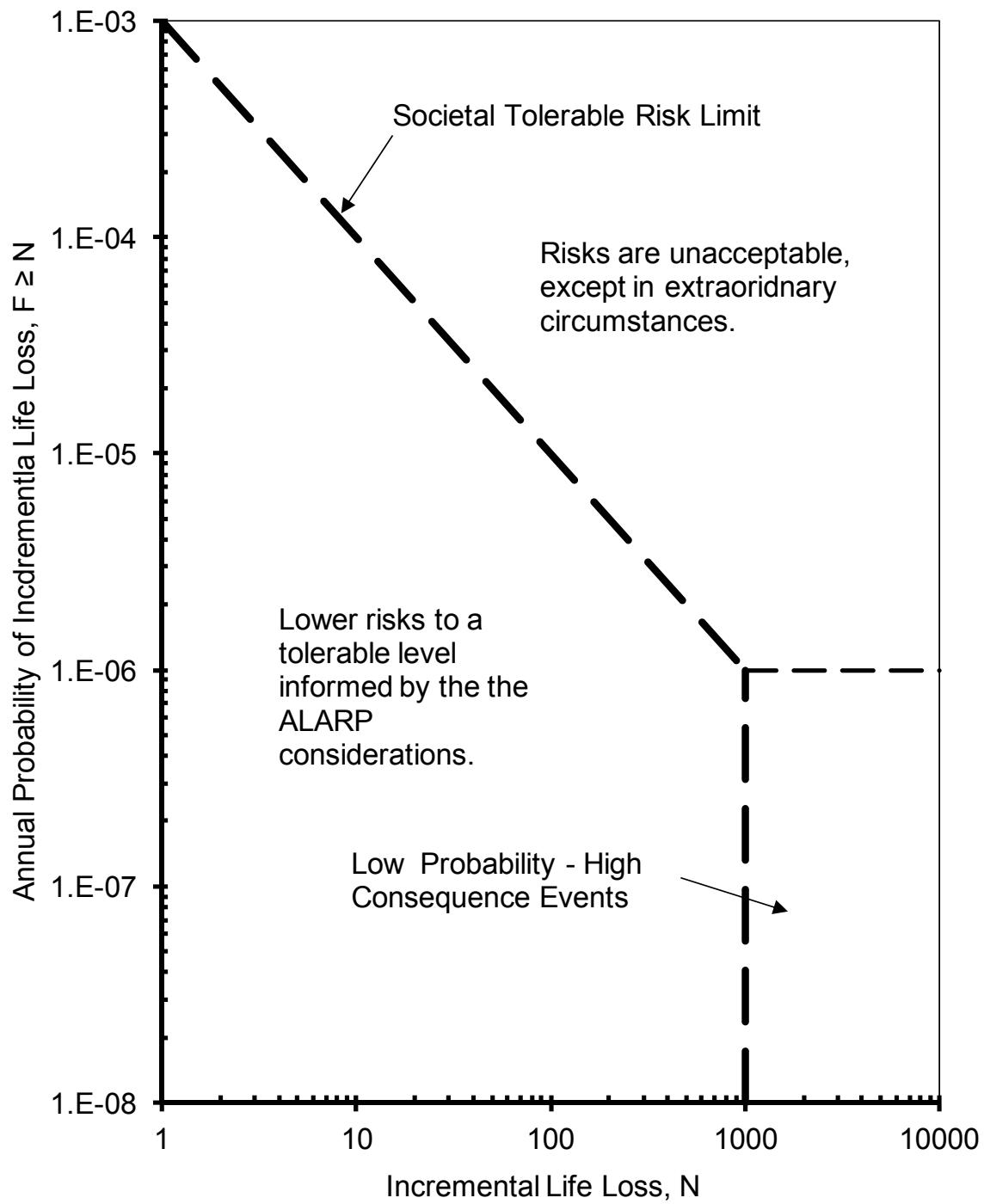


Figure 3A-5. Bureau of Reclamation (2011) Risk Guidelines



3A-6. U.S. Army Corps of Engineers (2014) Risk Guidelines