5. Relevant International Guidelines

5.1. Introduction to Summaries of International Guidelines

While the scope of this study specifically addresses guidelines for hydrologic safety of dams within the United States, there are several developments in the international arena that are particularly relevant to the study. Recently updated guidelines in Australia and Canada were reviewed and are summarized in the following sections to provide a glimpse of how other countries' guidelines are changing. This literature review is by no means intended to be a comprehensive overview of international guidelines.

5.2. ANCOLD Guidelines on Selection of Acceptable Flood Capacity for Dams

In Australia, there is no federal legislation on dam safety. Therefore, Australian jurisdictions that have dam safety regulations in place including Victoria, New South Wales, Queensland, and the Australian Capital Territory (ACT) are responsible for developing their own dam safety guidelines. In order to provide a basis for consistency throughout Australia in the assessment of hydrologic safety of dams, the Australian National Committee on Large Dams (ANCOLD) established a Working Party in 1994 to revise the existing standards based guidelines in light of moves to integrate risk assessment into dam safety procedures.

The prior *1986 ANCOLD Guidelines on Design Floods for Dams* introduced the concept of incremental flood hazard categories for ranking the recommended design flood against consequences of a dam failure. At that time risk analysis was being considered; however, the methodology was not well developed. As a result, the 1986 guidelines did not propose the use of risk analyses for dams where lives were at risk. In 1987, the guidelines were revised to include *Australian Rainfall and Runoff*, which included a chapter on estimation of extreme floods.

ANCOLD then led the way internationally in the development of acceptable risk criteria in dam safety and published *Guidelines on Risk Assessment* in 1994. These guidelines provided a basis for integrating risk assessment into dam safety. At that time it became apparent that procedures for risk-based dam safety evaluation were still in the development phase worldwide, and the 1994 risk guidelines needed review. In addition flood estimation procedures for risk-based dam safety evaluation were required to provide flood probabilities for application in risk assessment.

In 2000, *ANCOLD Guidelines on Selection of Acceptable Flood Capacity for Dams* was published to provide more appropriate and consistent guidance within a risk process for dam safety evaluation under floods. The 2000 guidelines superseded the 1986 guidelines in accordance with the ANCOLD aim for integration of risk assessment into the guidelines. The estimation of extreme floods and associated assigned probabilities are based on the procedures developed for Australia in 1999. A point reiterated in the 2000 ANCOLD guidelines is that spillway capacity should be

assessed within the total load context and not as a separate case so that all safety issues can be identified and an optimum solution can be developed.

The guidelines include a deterministic “fall-back option” that the owner can adopt instead of the quantitative risk assessment approach. The fall-back option is intended to be more conservative and result in a higher design requirement and cost to bring the dam up to the required standard than the alternative risk assessment procedure. The fall-back option involves first determining the Hazard Category based on consequences and then assigning the acceptable flood capacity based on the assigned return period for the selected Hazard Category rating. The hazard category rating system adopted by Queensland in 2007 based on the ANCOLD Guidelines as well as the corresponding range of acceptable flood capacities for the different hazard categories are presented in Table 5-1. The guidelines also specify flood surcharge “wet” and “dry” freeboard requirements.

Table 5-1 Queensland Hazard Category Rating System [State of Queensland, 2007]

Incremental Population at Risk (PAR)	Severity of Damage and Loss											
	Negligible		Minor			Medium			Major			
$2 \le PAR \le 10$			5.0×10^{-4}	Significant		5.0×10^{-4}	Significant		1.0×10^{-4}	High C		1.0×10^{-5}
		Low										
			5.0×10^{-4}			1.0×10^{-4}			1.0×10^{-4}			C
$10 < PAR \le 100$			5.0×10^{-4}	Significant		1.0×10^{-4}	High C		1.0×10^{-4}	High B		1.0×10^{-5}
			1.0×10^{-4}			1.0×10^{-4}	C		C	B		B
$100 < PAR \le 1000$							A	High A	A		High A	A
							A		A			A
$PAR > 1000$										PMF	Extreme	PMF
										PMF		PMF

If in this region, go to the next highest severity of Damage and Loss category for the same PAR

Where

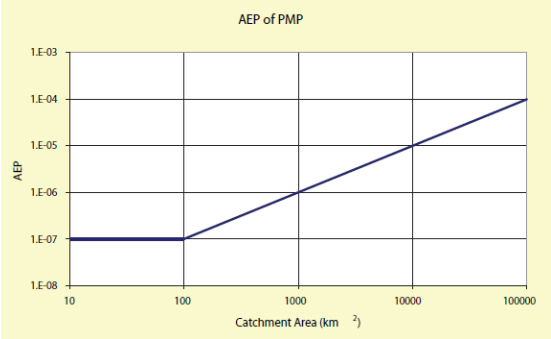
A = PMP Design Flood

B = PMP Design Flood or 10^{-6}, whichever is the smaller flood event

C = PMP Design Flood or 10^{-5} whichever is the smaller flood event

Note that the probability of the PMP Design Flood is a function of the catchment area.

Table 2: Required range of A cceptable Flood Capacities for different hazard categories



Supplied courtesy of the Department of Environment and Resource Management, Queensland, Australia.
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The ANCOLD *Guidelines on Risk Assessment* was revised in 2003. Victoria, New South Wales, Queensland subsequently adopted the ANCOLD guidelines with minor differences in the limits for tolerability of risk and other provisions. The Victorian regulations require risk assessments for high hazard dams. Risk assessments are optional for the Queensland and New South Wales regulations [Sih et al, 2010]. Reclamation and USACE have recently revised and adopted elements of the ANCOLD guidelines in the formulation of their new risk-based guidelines.

5.3. Canadian Dam Association Guidelines (2007)

Regulation of dams in Canada is primarily a provincial responsibility. Federal agencies have limited jurisdiction related to international boundary waters with the United States and some responsibility for security of critical infrastructure. In 1995, after three years of effort by working groups, the Canadian Dam Safety Association (CDA) published *Dam Safety Guidelines*. In 1999, the CDA issued a revision, and in 2007, the CDA published its most recent guidelines that include a companion series of technical bulletins on dam safety. The technical bulletins suggest methodologies and procedures for use by qualified professionals as they perform dam analyses and safety assessments.

The CDA guidelines include a dam classification system based on failure consequences and discuss both the traditional standards-based approach and the risk-based approach to dam safety decision making. However, IDF requirements are only specified using a deterministic assessment. *Technical Bulletin 6 – Hydrotechnical Considerations for Dam Safety* presents details of the CDA guidelines for selecting the inflow design flood (IDF) and freeboard. The suggested CDA IDF for use in deterministic assessments is presented in Table 5-2. The suggested CDA dam classification scheme is shown in Table 5-3. The IDFs presented in Table 5-2 make reference to the 1 in 1,000-year flood, and ratios of 1/3 and 2/3 between the 1 in 1,000-year flood and the PMF. The CDA guidelines indicate that beyond the 1 in 1,000-year flood, floods cannot be obtained by flood statistics methods. The proposed method consists of interpolating the flood hydrographs rather than the flood peaks or volumes since experience has shown unacceptable distortions using these parameters.

Selecting the IDF using quantitative risk analyses is not discussed and appears to be discouraged because of the inability to accurately assign a probability to extreme floods. As noted in Table 5-2, “extrapolation of flood statistics beyond the 1 in 1,000 year flood is discouraged.”

Provinces, like British Columbia, have adopted the CDA guidelines with only minor modifications. Table 5-4 shows the downstream consequence classification system presented in the 2009 *British Columbia Dam Safety Guidelines*. Minimum design standards for determining the IDF for dams constructed after 2008 are identical to those shown in Table 5-2. The British Columbia guidelines note that the 1999 CDA dam safety guidelines were updated in 2007 and that this update resulted in, among other things, a more stringent suggested annual exceedance probability (AEP) for determining the IDF. For dams constructed prior to 2008, the British Columbia Dam Safety

Program allows dam design engineers to use the 1999 CDA Dam Safety Guidelines. Since the 2007 CDA guidelines use a different dam classification table than the British Columbia Dam Safety Regulations, design engineers are instructed to contact their Dam Safety Officer for the policy on how to use the two classification tables together.

Table 5-2 Suggested CDA Inflow Design Flood for Use in Deterministic Assessments [CDA, 2007]

Consequence Class	IDF
Low	1/100-year
Significant	Between 1/100 and 1/1000-year (Note 1)
High	1/3 between 1/1000-year and PMF (Note 2)
Very High	2/3 between 1/1000-year and PMF Note 2)
Extreme	PMF

Note 1. Selected on basis of incremental flood analysis, exposure and consequence of failure.
Note 2. Extrapolation of flood statistics beyond 1/1000-year flood (10^{-3} AEP) is generally discouraged. The PMF has no asssociated AEP. The flood defined as "1/3 between 1/1000-year and PMF" or "2/3 between 1/1000 year and PMF" has no defined AEP.

Table 5-3 Suggested CDA Dam Classification System [CDA, 2007]

Dam class	Population at risk [note 1]	Incremental losses		
		Loss of life [note 2]	Environmental and cultural values	Infrastructure and economics
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services
Significant	Temporary only	Unspecified	No significant loss or deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes
High	Permanent	10 or fewer	Significant loss or deterioration of *important* fish or wildlife habitat Restoration or compensation in kind highly possible	High economic losses affecting infrastructure, public transportation, and commercial facilities
Very high	Permanent	100 or fewer	Significant loss or deterioration of *critical* fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances)
Extreme	Permanent	More than 100	Major loss of *critical* fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services (e.g., hospital, major industrial complex, major storage facilities for dangerous substances)

Note 1. Definitions for population at risk:

None—There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure.

Temporary—People are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

Permanent—The population at risk is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents); three consequence classes (high, very high, extreme) are proposed to allow for more detailed estimates of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).

Note 2. Implications for loss of life:

Unspecified—The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

Table 5-4 British Columbia Dam Safety Dam Classification System [British Columbia, 2009]

Rating	Loss of Life	Economic and Social Loss	Environmental and Cultural Losses
VERY HIGH	Large potential for multiple loss of life involving residents and working, travelling and/or recreating public. Development within inundation area (the area that could be flooded if the dam fails) typically includes communities, extensive commercial and work areas, main highways, railways, and locations of concentrated recreational activity. Estimated fatalities could exceed 100.	Very high economic losses affecting infrastructure, public and commercial facilities in and beyond inundation area. Typically includes destruction of or extensive damage to large residential areas, concentrated commercial land uses, highways, railways, power lines, pipelines and other utilities. Estimated direct and indirect (interruption of service) costs could exceed $100 million.	Loss or significant deterioration of nationally or provincially important fisheries habitat (including water quality), wildlife habitat, rare and/or endangered species, unique landscapes or sites of cultural significance. Feasibility and/or practicality of restoration and/or compensation is low.
HIGH	Some potential for multiple loss of life involving residents, and working, travelling and or recreating public. Development within inundation area typically includes highways and railways, commercial and work areas, locations of concentrated recreational activity and scattered residences. Estimated fatalities less than 100.	Substantial economic losses affecting infrastructure, public and commercial facilities in and beyond inundation area. Typically includes destruction of or extensive damage to concentrated commercial land uses (highways, railways, power lines, pipelines and other utilities). Scattered residences may be destroyed or severely damaged. Estimated direct and indirect (interruption of service) costs could exceed $1 million.	Loss or significant deterioration of nationally or provincially important fisheries habitat (including water quality), wildlife habitat, rare and/or endangered species, unique landscapes or sites of cultural significance. Feasibility and practicality of restoration and/or compensation is high.
LOW	Low potential for multiple loss of life. Inundation area is typically undeveloped except for minor roads, temporarily inhabited or non- residential farms and rural activities. There must be a reliable element of natural warning if larger development exists.	Low economic losses to limited infrastructure, public and commercial activities. Estimated direct and indirect (interruption of service) costs could exceed $100,000.	Loss or significant deterioration of regional important fisheries habitat (including water quality), wildlife habitat, rare and endangered species, unique landscapes or sites of cultural significance. Feasibility and practicality of restoration and/or compensation is high. Includes situations where recovery would occur with time without restoration.
VERY LOW	Minimal potential for any loss of life. The inundation area is typically undeveloped	Minimal economic losses typically limited to owners property and do not exceed $100,000. Virtually no potential for future development of other land uses within the foreseeable future.	No significant loss or deterioration of fisheries habitat, wildlife habitat, rare or endangered species, unique landscapes or sites of cultural significance.

6. Prior State and Federal Surveys Related to Design Flood Selection

6.1. Background

As design practices and regulatory guidelines relating to the selection of a design flood have developed over the past several decades, multiple organizations and individuals have striven to understand what the industry standard was at a particular point in time. The use of surveys has been a common tool in identifying current dam safety practices. Several past surveys regarding design flood selection are summarized in this chapter. Each survey provides a snapshot in time of dam safety practices and regulations as well as common opinions and ideologies of the dam safety community. A careful review of each of the surveys is helpful in identifying the trends and changes regarding the hydrologic safety of dams over the past 40 years.

6.2. USCOLD – 1970

In the late 1960s, the U.S. Committee on Large Dams performed a survey of dam design practices for sizing spillways in the United States. Surveys were solicited from both federal and state dam safety agencies, and results were published in a 1970 report "Criteria and Practices Utilized in Determining the Required Capacity of Spillways."

It was reported that all respondents to the survey followed policies discouraging the use of risk analysis when designing high hazard dams. Without exception, respondents agreed that the prevention of overtopping during extreme flood events is of such importance that the required cost is justified. It was also noted that the policies generally accepted at the time were not radically different from those from 20 or more years previous to the study, although procedures and techniques had improved.

6.3. National Research Council – 1985

As part of a study entitled "Safety of Dams: Flood and Earthquake Criteria" performed by the Committee on Safety Criteria for Dams of the Water Science and Technology Board of the NRC's Commission on Engineering and Technical Systems, inquiries regarding current dam safety provisions were made to federal agencies most concerned with dams, state dam safety units, several prominent dam engineering firms, and other organizations with interests in dam safety. The data from 10 federal agencies, 35 state and local agencies, 9 private firms, and 4 professional engineering societies were used to determine the state of the practice in 1985.

The survey found a broad range of classification criteria being used at the time. Most dam classification systems were based on dam height, volume of water impounded, the extent of

development in the downstream dam failure hazard area, or a combination of the preceding characteristics. The summary notes that:

> *"While it appears that many of the differences in dam classification systems are the result of arbitrary choices of regulatory authorities, it also appears that most of the classification systems have been structured to meet the perceived needs of the issuing agency or state government"* [NRC, 1985].

In regards to spillway capacity, the survey found that the majority of design criteria were based on deterministic estimates of the PMP or PMF, some percentage of the PMP or PMF, and probabilistic flood events with a return period of 100 years or less frequent. The Soil Conservation District and the state of West Virginia reported using mixed criteria based upon both probabilistic and deterministic estimates. The only reports of probabilistic floods less frequent than the 100-year event occurred in California (1,000 year flood event) and Michigan (200-year flood event). A summary of spillway capacity criteria used by various U.S. states and agencies in 1985 is included in Table 6-1.

Table 6-1 Spillway Capacity Criteria Reported to Be in Use by Various U.S. Agencies in 1985 [NRC, 1985]

Deterministic Criteria	Mixed Criteria	Probabilistic Criteria
Criteria specifying rainfalls		
PMP	P100 + 0.40 (PMP – P100)	2.25 P100
0.90 PMP	P100 + 0.26 (PMP – P100)	1.50 P100
0.80 PMP	P100 + 0.12 (PMP – P100)	P100
0.75 PMP	P100 + 0.06 (PMP – P100)	P50
0.50 PMP		P10
0.45 PMP		
0.40 PMP		
0.33 PMP		
0.30 PMP		
0.25 PMP		
0.225 PMP		
0.20 PMP		
0.10 PMP		
Criteria specifying floods		
PMF		1,000-year flood
0.75 PMF		200-year flood
0.50 PMF		100-year flood
0.40 PMF		50-year flood
0.30 PMF		
0.25 PMF		
0.20 PMF		

Criteria specific to each agency included in this study are published within the report. The following key points regarding spillway capacity design were noted:

- There was a fair consensus on the spillway requirements for large, high-hazard dams. The use of PMP or PMF estimates for such dams predominated, although many state regulatory agencies indicated that their standards did not require the full PMP or PMF.
- There was a much greater diversity of hydrologic criteria for the safety of classes of dams other than large, high hazard dams.
- While simple hazard rating categories based on downstream development may be useful for identifying dams for high-priority safety evaluation and study, they do not reflect the potential for incremental loss of life and damage caused by failure of a dam due to an inadequate spillway when a river is already in flood.
- Though not included in most published criteria, the use of incremental damage assessments was growing in acceptance and used to establish the required spillway capacity.
- New concepts and improved methods for estimating floods have resulted in generally larger flood estimates and future estimates of magnitude for extreme floods can be expected to increase. However, unless the runoff characteristics of the watershed were to change, increments in future flood estimates should be less than those noted in the past. There have been instances where more intensive hydrometeorological studies have resulted in reductions in estimates of PMP by earlier investigations.
- A dam designed for the PMF using the PMP does not provide absolute assurance that the dam is safe for every possible flood.
- The study noted that the use of arbitrary criteria such as a percentage of the 100-year storm, fraction of the PMF, or combinations of the PMF and probability based floods was common, even though there is no documented scientific rationale for such approaches.

For new high-hazard dams, the Committee recommended the PMF be adopted for the SDF unless risk analyses that examine the incremental impact of overtopping and dam failure during an extraordinary flood demonstrate that little or nothing is gained by such a high standard. The SDF would be the smallest value that ensures that a dam breach results in no significant increase in potential for loss of life or major property damage.

For existing high-hazard dams, the Committee concluded that there was no universally satisfactory approach to establishing spillway capacity criteria. The Committee therefore recommended that risk-based analysis be considered for existing high-hazard dams “for which the PMF is not required.” A section describing risk-based analyses was included in the report.

No specific recommendations were made by the Committee for spillway design requirements for intermediate hazard and low hazard dams.

Additional recommendations made by the Committee are summarized in Section 4.9.

6.4. Dubler Thesis, Colorado State University – 1995

James R. Dubler published the thesis "Dam Safety Policy for Spillway Design Floods" as part of his Master of Science degree at Colorado State University in 1995. Representatives of 46 state dam safety agencies provided responses to a survey included in the thesis.

The study found that disagreement concerning the selection of the SDF among professionals still existed. At the time of the survey, risk analysis was not popular in the professional community, and most states' guidelines for the selection of the SDF were based on a prescriptive approach. The survey also explored a variety of topics related to the SDF and risk analysis including incremental damage analysis, early warning systems, the development of probable maximum flood estimates, downstream development controls, advantages and disadvantages concerning risk analysis, and opinions regarding the level of conservatism required for spillway design.

Dubler made the following conclusions in his thesis:

- The use of prescriptive standards for important structures usually implies adoption of the "no-risk" stance. This is inappropriate. That is not to say use of the PMP/PMF as a design criterion is necessarily inappropriate, but it is inappropriate to make that selection on the basis of "no-risk."
- It is not reasonable to have different probabilities of failure for different aspects of dam design.
- It is not reasonable to have different degrees of conservatism for different sorts of risks facing society.
- The risk analysis approach is not popular in the professional community. Perhaps this is partly because "risk" is a bad word. Perhaps we need a more appealing label, such as "balanced design."
- There are those who believe it is wrong for public policy to explicitly acknowledge that for some stated endeavor a certain degree of risk exists. The unfortunate fact is that risks do exist and accidental deaths do occur. We as a society must decide what portion of our resources we are willing to allocate to reduce such deaths. Clearly, certain expenditures involving construction or retrofitting of spillways are not justifiable. It is the moral duty of the engineer, and in fact of everyone, to make optimum use of resources.

6.5. Paxson and Harrison – 2003

In 2003, Greg Paxson and John Harrison of Schnabel Engineering, Inc. performed an independent survey of state dam safety officials as part of a technical paper entitled "Hydrology and Hydraulics for Dams: State of the Practice or Practice of States?" All 50 states were included in the study which placed an emphasis on the hydrologic and hydraulic methods and models used.

The survey revealed that a total of 76 percent of the states would allow the development of site specific PMP studies. Eighty-eight percent of the states would allow the use of incremental damage

assessment to establish the SDF. Only 43 percent would allow the use of rigorous risk-based analysis. It was noted that the allowance of these practices did not necessarily equate to their common use.

The authors of the technical paper commented that standardization of certain practices not dependent upon regional conditions would likely be beneficial to the dam safety community. Standard criteria could include approved hydrologic models, freeboard requirements, reservoir inflow and initial water surface elevation criteria for dam failure inundation analyses, and criteria for incremental damage analysis.

6.6. ASDSO Surveys

The Association of State Dam Safety Officials has performed numerous surveys of the state dam safety agencies over the past decade. Recent material includes the "State Dam Safety Dam Size Classification Schemes" and "State Dam Safety Hazard Potential Classification" which were both published in 2010 and are included in Appendix F. On an annual basis, ASDSO collects information on states' public awareness, education, staffing, training, budgets, legislation/regulations, program improvements, litigation, dam failures/incidents, dam removals, research, and other activities.

7. 2011 Hydrologic Safety of Dams Survey and Database

7.1. Questionnaire Distribution and Database Compilation

The purpose of this report is to document the present state of the practice for evaluating the hydrologic safety of dams, including inventorying current practices used by state and federal agencies. As a significant portion of this effort, a detailed questionnaire was prepared and distributed to all state dam safety agencies as well as any federal agencies which own, regulate, or assist in the design of dams. Members of the research team initially reviewed each agency's published policies and guidelines and completed applicable portions of the questionnaire. Respondents were requested to complete the survey and verify any responses initially completed by the research team. Electronic copies of the questionnaire were distributed to potential respondents in February 2011. Questionnaires were completed by respondents and returned to the research team by May 2011.

As questionnaires were returned, a member of the research team reviewed each response to ensure its accuracy and completeness. If needed, the respondent was contacted to clarify their responses. In a few cases, questionnaires were edited to create consistency between responses, thereby enabling comparison and analysis of the results. For example, when asked if the agency had hazard classification criteria, the survey allowed several responses including "Yes (High, Significant, and Low)." Several agencies responded "Yes (Other)" and commented that they utilized classification system consisting of high, moderate, and low hazards. In these cases, the terms "moderate" and "significant" were judged to be equivalent and interchangeable and the response was edited by the research team accordingly. All responses were incorporated into an electronic database which facilitated analysis of the survey results.

The questionnaire addressed many important issues related to the hydrologic safety of dams including dam classification criteria, determination of the SDF, allowable methodologies and software, consideration of future development, incremental damage assessment, use of early warning systems, current practices related to risk analysis, and agencies' ability and receptiveness to perform risk analysis. Thirteen questions were included in an "off-the-record" or anonymous portion of the survey due to their potentially sensitive nature. A copy of the survey questionnaire and corresponding answer choices is included in Appendix C.

7.2. Response

Of the 63 surveys distributed, a total of 58 were completed. Surveys were completed by the appropriate dam safety agency from all 50 states, as well as Puerto Rico, with exception of Alabama and Florida. The State of Alabama does not currently have a dam safety program and therefore did not provide a response. Florida's Dam Safety Program elected to not complete the

questionnaire due to the fact that dams within the state are regulated separately by each water management district. Each of the five districts within the state has different spillway design standards.

Of the federal agencies, respondents included:

- Bureau of Indian Affairs
- Federal Energy Regulatory Commission
- Mine Safety and Health Administration
- Natural Resources Conservation Service
- Tennessee Valley Authority
- U.S. Army Corps of Engineers
- U.S. Bureau of Reclamation
- U.S. Forest Service
- U.S. Fish and Wildlife Service

The National Park Service declined to participate. The Bureau of Land Management and U.S. Nuclear Regulatory Commission did not respond to the survey request.

Chapters 8 and 9 of this report present the key findings of this survey effort in relation to current hydrologic design practices of both the federal and the state agencies, respectively. "On-the-record" portions of questionnaires completed by respondents and finalized by the Research Team are included in Appendix C.

8. Summary of Current Federal Hydrologic Design Guidelines

8.1. Background

Historically, a few key federal agencies have led the way in developing dam safety regulations and design standards. Agencies that have typically been at the forefront of dam safety include the Federal Emergency Management Agency, Bureau of Reclamation, Army Corps of Engineers, and the Natural Resources Conservation Service. Summaries of the hydrologic design practices of these agencies are provided in this chapter. A compilation of pertinent federal publications and guidance documents are included in Appendix D. Policies of other federal agencies who responded to the Hydrologic Safety of Dams Survey are also reviewed.

8.2. Overview of Dam Classification and Spillway Design Criteria

8.2.1. Definition of Regulatory Dam

In identifying non-jurisdictional or non-inventory dams, all federal agencies other than FERC and the Mine Safety and Health Administration (MSHA) follow the definition outlined in FEMA's Federal Guidelines for Dam Safety. FEMA's guidelines specify that a dam is:

> *"…any artificial barrier, including appurtenant works, which impounds or diverts water and which (1) is twenty-five feet or more in height from the natural bed of the stream or watercourse measured at the downstream toe of the barrier or from the lowest elevation of the outside limit of the barrier if it is not across a stream channel or water course, to the maximum water storage elevation or (2) has an impounding capacity at a maximum water storage elevation of fifty acre-feet or more. These guidelines do not apply to any such barrier which is not in excess of six feet in height regardless of storage capacity, or which has a storage capacity at maximum water storage elevation not in excess of fifteen acre-feet regardless of height. This lower size limitation should be waived if there is a potentially significant downstream hazard"* [FEMA, 2004].

The MSHA's non-coal program area also follows these guidelines; however, for the coal program, any impoundment less than 5 feet high or less than 20 feet high with a storage volume of less than 20 acre-feet is considered non-jurisdictional. FERC considers any dam included in a FERC license to be a jurisdictional dam.

8.2.2. Dam Classifications and Selection of the Spillway Design Flood

All of the federal agencies responding to the survey indicated the use of hazard classification criteria. All of these agencies use a three-class system consisting of high, significant, and low hazard. Most of the agencies defined "Significant Hazard" as having *no potential for loss of life,*

though extensive economic losses would be expected. Under these agencies, any dam creating a hazard to human life would be classified as "High Hazard." The Bureau of Indian Affairs (BIA) definition of a significant hazard dam states that between 1 and 6 lives would be at risk or significant property damage could occur if the dam failed. USACE indicated that loss of life is "not probable" during the failure of a significant hazard dam.

The only federal agencies indicating the use of size classification criteria were the U.S. Fish and Wildlife Service (USFWS) and MSHA. Both of these agencies use a combination of hazard and size classification to determine the SDF. Most of the other federal agencies prescriptively assign the SDF based on hazard classification only. The only exceptions to this are USACE and Reclamation who are leading the way in developing spillway design criteria using risk analysis. Additionally, the BIA indicated that the use of risk analysis in connection with its prescriptive hazard classification system was acceptable.

With the exception of the Bureau of Reclamation, all federal agencies use the same criteria for both the design of new dams and the evaluation and rehabilitation of existing dams. Reclamation indicated that the application of updated design guidelines to an existing dam would vary by project after considering the amount of risk reduction, feasibility of the modification, and cost/benefit analysis results.

8.2.3. Design Criteria

By way of the 2011 Hydrologic Safety of Dams survey, several key points were identified concerning the practices of federal agencies. These are as follows:

- For PMP/PMF designs, most federal agencies determine the necessity for freeboard on a case-by-case basis. The Natural Resources Conservation Service (NRCS), TVA, and U.S. Forest Service (USFS) do not require freeboard for such designs.
- Most federal agencies either allow or encourage the use of early warning systems on Significant and High Hazard structures; however, they will not consider an early warning system as an alternative to designing a dam for the regulatory SDF. MSHA will allow storm runoff flood control dams to be designed to low hazard criteria if an early warning system is provided to prompt the evacuation of downstream personnel.
- All federal agencies permit the use of site specific PMP studies.
- The only federal agency that does not allow the use of an incremental damage assessment to establish the SDF is the TVA.
- While not all federal agencies have reviewed a risk-based design, there are no federal guidelines or regulations that forbid such designs. Federal agencies that have reviewed risk-based designs include the BIA, NRCS, USACE, Reclamation, and USFWS.

8.3. Summary of Guidelines from Select Federal Agencies

8.3.1. U.S. Bureau of Reclamation

As noted in Section 3.7, Reclamation appears to be the first federal agency worldwide to seriously apply risk-based decision making to dam safety. The Bureau began applying principles of risk analysis to dam safety as early as the 1980s. In 1985, the NRC Committee on Safety Criteria for Dams reported that while many Reclamation dams were held to the industry standard PMF, the concepts of incremental damage analysis and even the beginnings of full-fledged risk analysis (including consideration of social, environmental, and political effects of dam failure in additional to incremental damage and loss of life) were incorporated in Reclamation design criteria.

Since that time, Reclamation has moved away from deterministic design flood standards and has emerged as a major promoter of risk analysis. In utilizing risk analysis, each dam site and structure is considered individually with the SDF being determined on a case-by-case basis. Under current Reclamation practice, any modifications to spillway design capacity would follow a risk-based approach using Reclamation's Risk Analysis Best Practices Manual and would vary by project. Modifications to existing structures must consider the amount of risk reduction, feasibility of modification, and cost/benefit analysis when selecting the design criteria. Reclamation's recommended guidelines for evaluating the need and urgency to implement risk reduction activities based on the estimated risk are shown in Table 8-1 and Figure 8.1. Incremental damage analysis is used when appropriate but not required.

In 2006, Robert E. Swain, John F. England, Jr., and Kenneth L. Bullard of Reclamation published Guidelines for Evaluating Hydrologic Hazards as a guidance document for generating hydrologic hazard information to be used in evaluating the hydrologic risk at dams. This document outlines a procedure for developing hydrologic hazard curves using a combination of seven hydrologic methods. These methods include the use of flood frequency analysis with historical and paleoflood data as well as the development of a PMF using published HMR and Reclamation guidelines. Other significant contributions and guidelines that Reclamation has published over the past two decades to facilitate application of risk analysis to dam safety are noted in Section 3.7.

Table 8-1 Bureau of Reclamation Risk Reduction Guidance [Adapted from Reclamation, 2003]

Guidance for Estimated Risk	
Estimated risk is portrayed to be greater than 0.01 lives per 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, 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 0.01 and .001 lives per 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 decision makers 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 less than 0.001 lives per 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 decision making. Actions considered reasonable and prudent should be considered for implementation when the risk is in this range.

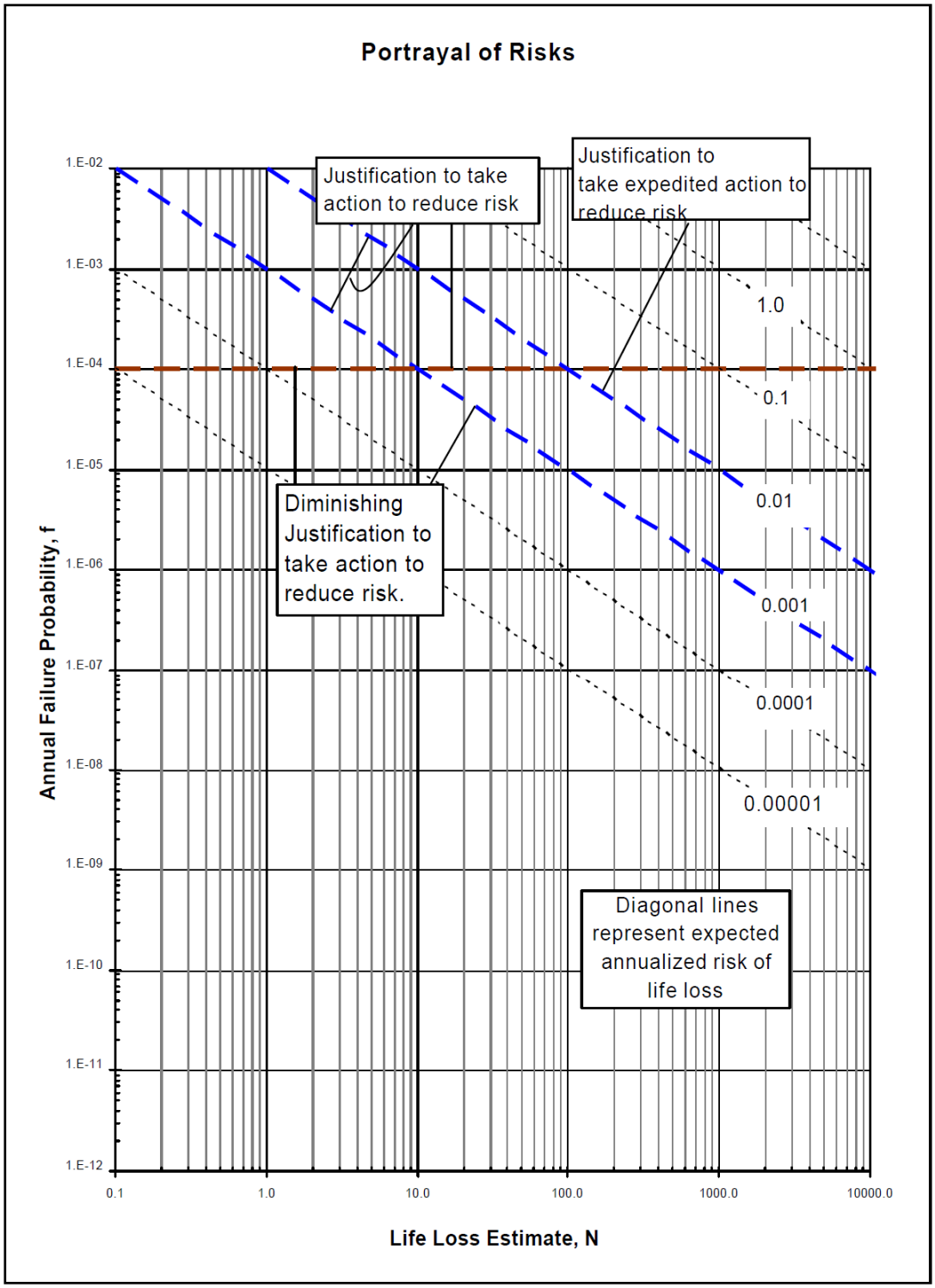

Figure 8.1 Reclamation f-N Chart for Displaying Probability of Failure, Life Loss, and Risk Estimates [Reclamation, 2003]

8.3.2. U.S. Army Corps of Engineers

The other major contributor to the development of risk-based dam safety standards in the United States has been the U.S. Army Corps of Engineers. USACE has published numerous guidance documents outlining policy and procedures related to dam safety. Under current guidelines, High hazard dams with potential life loss must pass 100% of the PMF per Standard 1 of ER 1110-8-2. Significant hazard dams with no probable life loss must pass major floods typical of the region without excessive damage or loss of operability per Standard 2 of ER 1110-8-2. Significant hazard dams with no incremental life loss due to dam failure must pass a minimum of 1/2 PMF per Standard 3 of ER 1110-8-2. Low hazard dams typically fall under Standard 4 of ER 1110-8-2 which requires rainfall-runoff probability analyses with no specific minimum requirement. These design standards are consistent with those that were utilized at the time of the 1985 NRC report.

One of the most recent USACE publications is ER 1110-2-1156 which is in draft form and is dated September 30, 2010. This publication provides an overview of the Dam Safety Program, provides guidelines and procedures for decisions, and discusses periodic assessments, inspections, and other items.

Some of the most relevant and state-of-the-art portions in ER 1110-2-1156 are the guidelines for assessing tolerable risk. The overall goal is to lower the residual risk to a tolerable level while also meeting project-specific requirements for what is practicable. The project-specific limits defined for what is practicable are termed “ALARP” which stands for “As Low As Reasonably Practicable.”

ER 1110-2-1156 presents the state-of-the-art guidelines for assessing tolerable risk including the application of the following concepts: “Tolerable Risk,” “Broadly Acceptable Risk,” “Tolerable Risk Range,” and “As-Low-As-Reasonably-Practicable” in a generalized and project specific tolerability of risk framework. A schematic illustrating these concepts is shown in Figure 8.2. Determining ALARP is ultimately a matter of judgment. General guidance is provided in ER 1110-2-1156 on how to satisfy the ALARP requirement.

The following four risk measures are evaluated under the USACE tolerable risk guidelines:

1. Annual Probability of Failure (APF)
2. Life Safety Risk
3. Economic Risk
4. Environmental and Other Non-Monetary Risk

Incremental consequences (consequences resulting from dam failure vs. consequences resulting without dam failure) are to be considered when performing quantitative risk analysis.

The USACE’s policy for the estimated annual probability of failure (APF) is that it is unacceptable to be greater than 1 in 10,000 (0.0001). An APF will be considered tolerable when it is less than 1 in 10,000 (0.0001) per year provided the other tolerable risk guidelines are met.

The USACE has identified three types of risk safety guidelines; (1) individual incremental life safety risk using probability of life loss, (2) societal incremental life safety risk expressed as a probability distribution of potential life loss (F-N chart), and (3) societal incremental life safety risk expressed as an Annualized Life Loss (ALL). For existing and new dams, the individual incremental life safety risk probability of life loss should be less than 1 in 10,000 and 1 in 100,000 per year, respectively. For existing dams the societal risk should be less than the tolerable risk limit line shown on Figure 8.3 and satisfy the ALARP requirements. Dams with failure risks that plot above a tolerable risk limit shown on Figure 8.3 are considered to have an unacceptable level of risk, except in exceptional circumstances. Annualized incremental societal life loss is evaluated based on the guidelines presented in Figure 8.4.

Risk informed hydrologic designs are permitted for flood damage reduction studies (e.g. levees, channel improvements, etc) per ER 1105-2-101. However, despite the significant efforts given to developing risk analysis for dam safety, risk-informed hydrologic designs are not permitted for dams under current USACE guidelines. Risk-informed hydrologic analyses for dams are used to prioritize risk reduction actions for dams in the USACE inventory and to inform decisions on incremental risk reduction actions for specific projects.

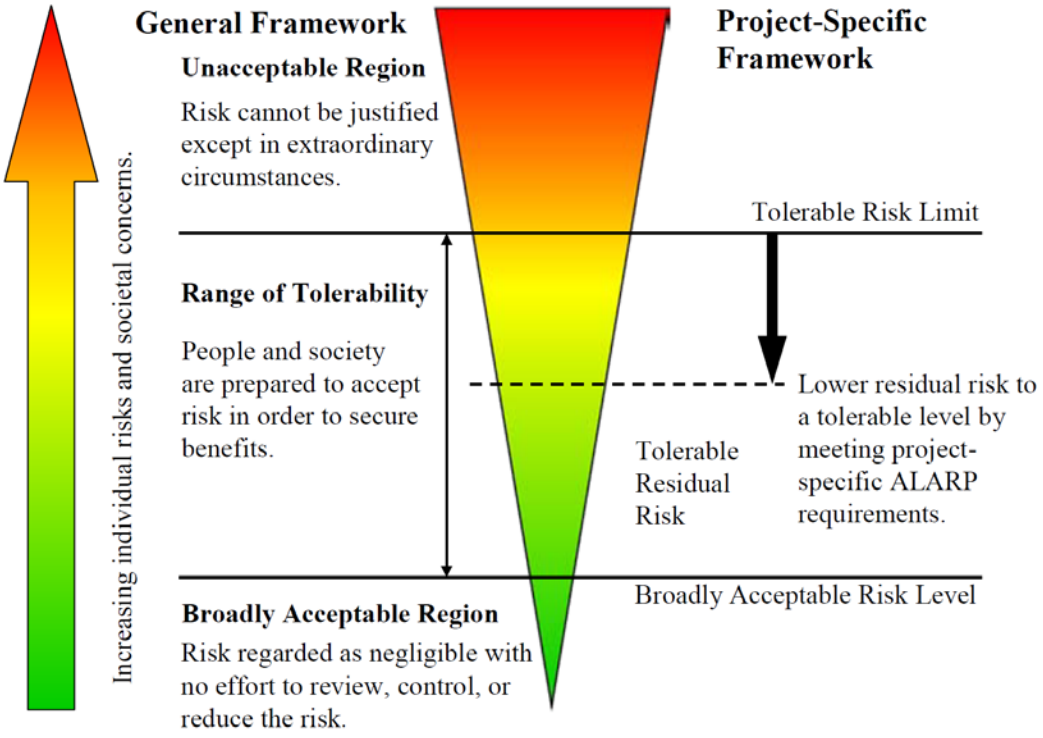

Figure 8.2 Generalized and Project Specific Tolerability of Risk Framework [USACE, 2010]

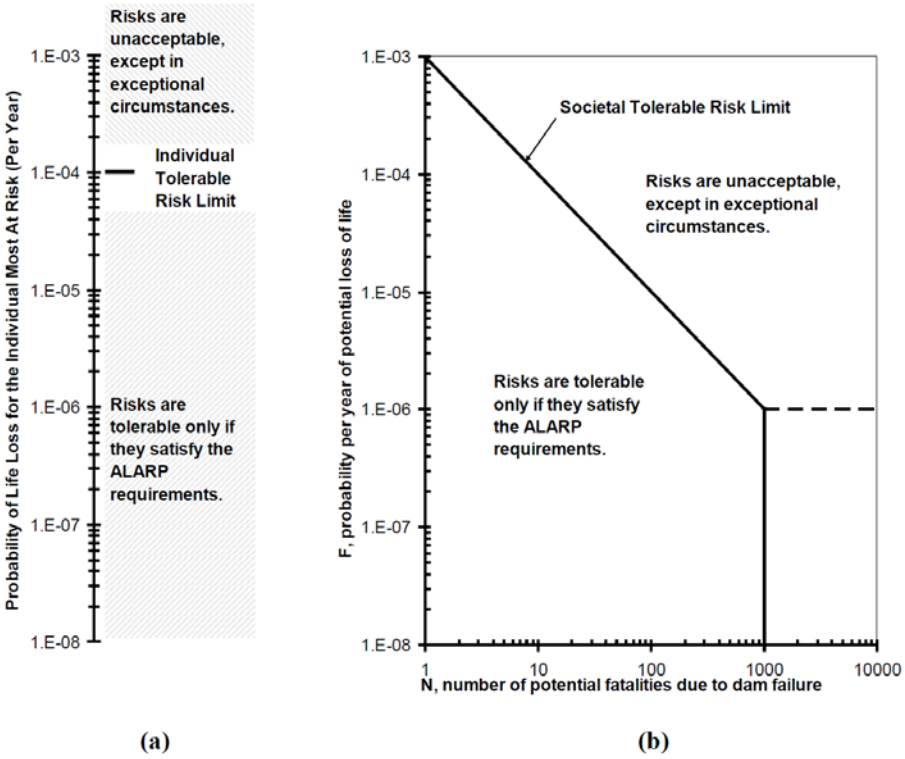

Figure 8.3 Individual Risk Guidelines (a) and Societal Risk Guidelines (b) for Existing Dams [USACE, 2010]

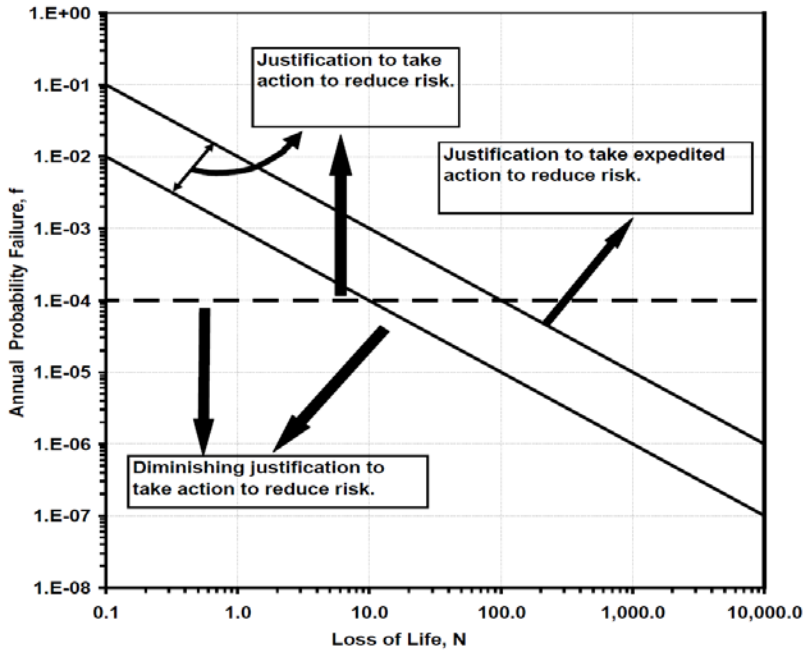

Figure 8.4 F-N Chart for Displaying Annual Probability of Failure and Annualized Life Loss [USACE, 2010]

8.3.3. Natural Resources Conservation Service

NRCS (previously known as the Soil Conservation Service or SCS) is not a regulatory agency, but rather an agency that provides financial and technical assistance to landowners and project sponsors in the evaluation, design, and installation of dams. SCS/NRCS guidelines were first developed in the 1930s. Since then the guidelines have evolved and are reviewed and updated on a continual basis. The NRCS has adopted a nationwide standard and allows state NRCS offices to revise the standards to make them more restrictive, but not less restrictive. Additionally, NRCS dams must meet all state and local regulations.

The NRCS has published numerous guidelines regarding the design and safety of dams. Technical Release 60 (TR-60) contains design requirements for earth dams and their associated spillways; National Engineering Handbook Part 630, Chapter 21 contains procedures for developing inflow hydrographs; and the National Conservation Practice Standard No. 378 contains design requirements for ponds and their associated spillways. NRCS design flood criteria from the TR-60 publication are listed in Table 8-2. These criteria are identical to those used by the NRCS in 1985 [NRC, 1985]. About 60 percent of NRCS dams are small, low hazard structures that provide water for livestock, fish and wildlife, recreation, fire control, or other related uses. Design criteria for these structures are listed in Table 8-3 as described in the National Conservation Practice Standard No. 378 for ponds.

NRCS encourages the use of a site-specific PMP where information is available. Where limiting physical site constraints exist, the NRCS does allow the use of incremental damage assessment in the rehabilitation of existing dams provided downstream land use controls are put in place to prevent voiding incremental risk assumptions [Hoeft et al, 2010]. NRCS will consider risk-based designs, but they are not a part of design guidelines.

Table 8-2 Minimum Auxiliary Spillway Capacity Criteria for Dams of the Natural Resources Conservation Service [NRCS, 2005]

Class of Dam	Product of storage X effective height	Existing or planned upstream dams	Precipitation data for [1]	
			Auxiliary spillway hydrograph	Freeboard hydrograph
Low [2]	less than 30,000	none	P_{100}	$P_{100} + 0.12(PMP - P_{100})$
	greater than 30,000		$P_{100} + 0.06(PMP - P_{100})$	$P_{100} + 0.26(PMP - P_{100})$
	all	any [3]	$P_{100} + 0.12(PMP - P_{100})$	$P_{100} + 0.40(PMP - P_{100})$
Significant	all	none or any	$P_{100} + 0.12(PMP - P_{100})$	$P_{100} + 0.40(PMP - P_{100})$
High	all	none or any	$P_{100} + 0.26(PMP - P_{100})$	PMP

[1] P_{100} = Precipitation for 100-year return period. PMP = Probable maximum precipitation
[2] Dams involving industrial or municipal water are to use minimum criteria equivalent to that of Significant Hazard Class.
[3] Applies when the upstream dam is located so that its failure could endanger the lower dam

Table 8-3 Minimum Auxiliary Spillway Capacity Criteria for Ponds of the Natural Resources Conservation Service [NRCS, 2002]

Drainage area (Ac.)	Effective height of dam[1] (Ft.)	Storage (Ac-Ft)	Minimum design storm[2]	
			Frequency (Years)	Minimum duration (Hours)
20 or less	20 or less	< than 50	10	24
20 or less	> than 20	< than 50	25	24
> than 20		< than 50	25	24
All others			50	24

1. As defined under "Conditions where Practice Applies".
2. Select rain distribution based on climatological region.

8.3.4. Federal Energy Regulatory Commission

FERC guidelines for the hydrologic safety of dams are consistent with FEMA's "Federal Guidelines for Dam Safety: Selecting and Accommodating Inflow Design Floods for Dams." These guidelines emphasize hazard evaluation as the primary means of determining the SDF. This emphasis includes the use of incremental damage analysis. FERC has also used information obtained from risk-based hydrologic analysis to aid in reviewing spillway designs. Although FERC has not utilized or developed risk analysis as fully as USACE or Reclamation, they have transitioned from a very deterministic and prescriptive approach to placing increasing emphasis on risk-related practices such as incremental damage analysis. A complete summary of FERC/FEMA's guidelines is included in Section 4.12.

8.3.5. Mine Safety and Health Administration

MSHA guidelines for the hydrologic safety of dams are based upon FEMA's "Federal Guidelines for Dam Safety: Selecting and Accommodating Inflow Design Floods for Dams." As noted previously, MSHA also utilizes a size classification system in conjunction with hazard classification to determine the appropriate SDF.

8.3.6. Tennessee Valley Authority

TVA guidelines are based upon FEMA's Federal Guidelines for Dam Safety as well as self-imposed criteria that TVA has developed over time. At present, TVA regulates 49 dams. They are in the process of creating a Dam Safety Governance organization which will implement guidelines for any impoundment within the TVA system which meets the definition of a dam within FEMA's Federal Guidelines for Dam Safety.

TVA typically selects the PMF as the appropriate SDF for dams with a high hazard classification. Significant and low hazard dams must pass the "TVA precipitation" as defined by a hydrometeorological design basis report developed for TVA by the National Weather Service. This precipitation is significantly less than the PMP. These SDF criteria are very similar to those used by the Authority in 1985 [NRC, 1985].

8.3.7. Bureau of Indian Affairs

BIA has custom developed dam safety guidelines based upon those published by Reclamation. In following with Reclamation guidelines, BIA determines the SDF using a combination of risk analysis and hazard classification. Under these guidelines, the SDF is typically defined as the largest flood which will cause incremental dam failure flooding. However, BIA reserves the right to select something smaller based on downstream conditions. Normally, the IDF will not be greater than a 10,000-year storm.

8.3.8. U.S. Forest Service

Both FEMA and USACE guidelines were consulted in the development of revised USFS dam safety guidelines. It is anticipated that the new guidelines will be completed in summer 2011. With the adoption of new guidelines, the Forest Service will discontinue the use of design flood criteria based upon a combination of size and hazard classification. SDF standards will be based entirely upon hazard classification. High Hazard dams will be required to pass the PMF, significant hazard dams will be required to pass 50% of the PMF, and low hazard dams will be required to pass the 100-year flood. Incremental damage analysis may allow spillway capacity to be reduced, but not any lower than the minimum thresholds which are as follows: 50% PMF (High Hazard), 100-year event (Significant Hazard), 50-year event (Low Hazard). Other than its use of incremental damage analysis, the revised USFS guidelines do not address risk analysis.

8.3.9. U.S. Fish and Wildlife Service

USFWS owns and self-regulates over 250 dams. SDF standards for these dams are based upon a combination of size and hazard classification. SDF criteria for varying size and hazard classes are as follows: all sizes of High Hazard dams (100% PMF); large, Significant Hazard dams (50-100% PMF); small or intermediate, Significant Hazard dams (50% PMF); large, Low Hazard dams (100-year to 500-year event); and small or intermediate, Low Hazard dams (100-year event). Incremental damage analysis may allow spillway capacity to be reduced, but not any lower than the 100-year flood. The Service indicated that risk-based hydrologic designs are permitted and have been used in the past.