9. Summary of Current State Hydrologic Design Guidelines

9.1. Introduction to State Guidelines

This chapter provides a summary of current state hydrologic design guidelines based on survey results, an examination of the actual guidelines, and review of prior state and federal surveys related to design flood selection. The information available from these sources was abundant, and only the most important and relevant findings are reviewed within this Chapter. Appendix C contains the completed surveys. A compilation of pertinent state regulations and guidance documents are included in Appendix E.

9.2. Origins and Status of State Guidelines

Most state dam safety officials who responded to the questionnaire indicated that their agency utilizes some sort of hydrologic design guidelines. Such guidelines are often published in the form of state administrative code, agency regulations and guidance documents, or a combination of both. Guidelines often hold the force of law. While guidelines are typically custom suited to each state and geographic region, the majority of state guidance documents draw heavily from federal dam safety regulations and design practices. The federal guidelines most commonly utilized by the states include those of FEMA, Reclamation, USACE, NRCS, and MSHA. A summary of when states adopted SDF criteria throughout the last century is shown in Figure 9.1 and shows that most states established SDF criteria prior to 1990.

In many states, dam safety guidelines are updated or revised on either a continual or recurring basis. However, of the 49 responding states, 31 indicated that they do not have any plans to update or revise their guidelines in the near future. At least 12 of the states had not updated spillway design guidelines in more than 15 years. It is noted that some states may consider altering requirements to be unfavorable due to potential cost consequences for dam owners in compliance with previous standards, potential for weakening of the overall standards due to lobbying, or the possible perception by the public that lives downstream are not worth the cost of protection.

In following with federal programs of the 1970s and 1980s, most states use a prescriptive approach to spillway design capacity. However, in the past few decades, a few states have adopted a more detailed, risk-based approach.

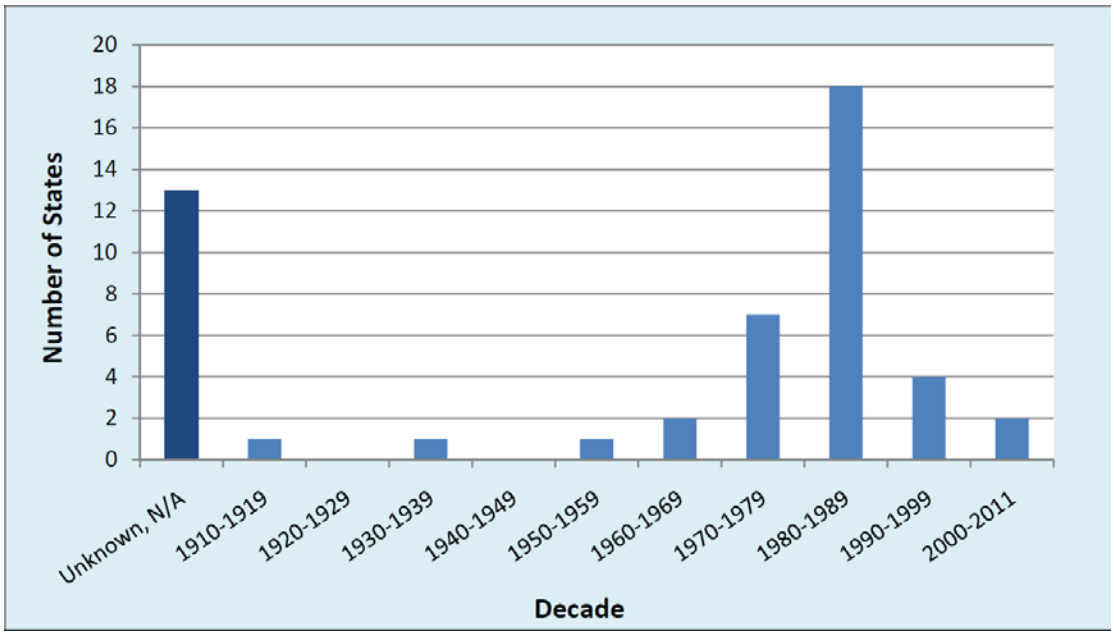


Figure 9.1 State Adoption of Spillway Design Flood Criteria by Decade

9.3. Dam Classification

States use many methods to identify and regulate dams within their jurisdiction. It appears that methods of dam classification have changed very little since the NRC's evaluation of flood design criteria in 1985. As noted in that report:

> *"There is considerable variety in the classification systems that have been adopted, and this variety often makes difficult any precise comparisons between criteria used by different agencies. Most systems for classifying dams specifically utilize dam height, volume of water impounded, and character of the development in the relevant downstream area as parameters in regard to probable effects of dam failure…*
>
> *"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].

This broad variance of size, hazard, and other classification criteria is described in Sections 9.3.1 thru 9.3.4. Since these criteria are often used in prescribing the SDF, classification criteria is a very important aspect of the hydrologic safety of dams.

9.3.1. Regulatory Dam

The definition of a regulatory or jurisdictional dam varies greatly from one state to another. Most states determine the status of an impoundment based either loosely or entirely upon the similar

definitions outlined in both the NID and FEMA's Federal Guidelines for Dam Safety (See Section 8.2.1). A total of 92% of the states define a jurisdictional dam by considering the storage volume of the impoundment. For 88% of the states, the height of the dam is also considered. Only 27% of the states mentioned the consideration of downstream hazard potential when determining if a dam is jurisdictional. Eight percent of states regulations included the drainage area in determining the regulatory status of an impoundment.

A few exceptions were also cited in determining the status of a dam. Under these exceptions, some states have defined farm ponds, road fills that do not normally impound water, dams associated with cranberry operations, dams used for manure storage, and dams not on watercourses as non-jurisdictional structures.

In the questionnaire, respondents were asked how their agency defines a "non-inventory or non-jurisdictional" dam. It is noted that in some states these two terms are distinctly defined. These states typically maintain an inventory of many small, limited hazard dams that do not necessarily fall under their regulatory jurisdiction.

9.3.2. Size Classification

In order to prescribe design standards or other regulations related to dams, several states utilize size classification criteria. Of the 49 surveys received, 29 states indicated that they utilize some sort of size classification system (See Figure 9.2). The names, number of size categories, and range limits vary extensively throughout the country. For example, depending on the state, a small-sized dam may be identified as a Class III, Class A, Class C, or small dam.

With respect to the number of size categories, the majority of size classification systems utilized by the states have only 3 classes (typically small, medium or intermediate, and large). Six states (Georgia, Kansas, Maryland, North Carolina, Ohio, and South Carolina) use size classification systems with 4 categories (either very large or very small in addition to the typical 3-class system). Four state/territories (Montana, New York, Puerto Rico, and Wisconsin) use size classification systems with only 2 categories (typically large and small). North Dakota is the only state that indicated a size classification system with 5 categories.

Size classification of a dam is typically based upon the height of the dam, the volume of storage, or some combination or product of the two values. The height and volume ranges vary dramatically. For example, the upper limit defining a small dam range anywhere from 10 feet high to 50 feet high and 12.5 acre-feet to 10,000 acre-feet. The most common definition of a small dam is less than 40 feet high storing less than 1,000 acre-feet. The lower limit defining a large dam is also extremely varied with the height ranging between 25 to 100 feet and the storage volume ranging between 50 acre-feet and 50,000 acre-feet. The most commonly used definition of a large dam is one having a height greater than 100 feet and storage greater than 50,000 acre-feet.

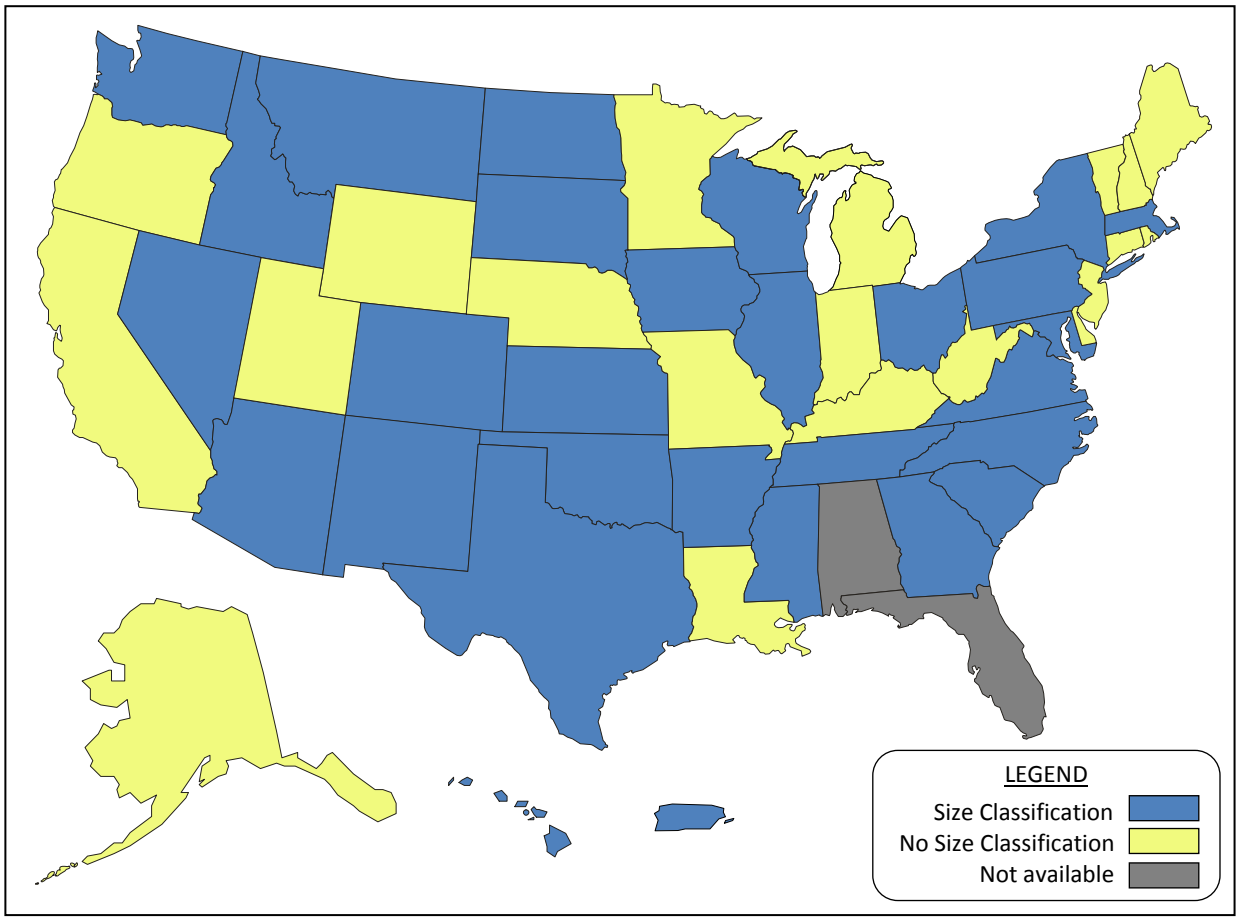


Figure 9.2 Size Classification Criteria within the United States and Puerto Rico

9.3.3. Hazard Classification

All of the states responding to the survey indicated the use of hazard classification criteria by their agency. A majority of 73% of respondents (36 states) use a three-class system consisting of high, significant, and low hazards. An additional 20% (10 states) have implemented a four-class system which typically includes a "Limited Hazard" classification below the "Low Hazard" class. Among the states using a three- or four-class system, there is a significant amount of disagreement concerning the definition of significant and high hazard dams. The key point of divergence is whether the probable loss of human life constitutes a high hazard rating. Sixty-five percent of the states have defined "Significant Hazard" as having *no potential* for loss of life, though extensive economic losses are expected. In these states, any dam creating a hazard to human life would be classified as "High Hazard." For the remaining 35% of the states, there are several ways that potential for loss of human life has been included in the definition of significant hazard. Some states define the loss of life potential as "few" or even designate a population at risk threshold for a significant hazard dam (such as 1 to 6 people or 1 or 2 habitable structures). Other states designate

that the failure or misoperation of a significant hazard dam will cause “possible loss of human life” (as opposed to “probable loss of human life” for a high hazard dam). Others state that the failure of a significant hazard dam has a “low probability” of causing loss of human life.

Georgia and Montana utilize a similar hazard classification system that is entirely based upon the likelihood of loss of human life. Dams are divided into two categories: those that will cause probable loss of life and those that will not. Connecticut is the only state to use a 5-class hazard classification system (Negligible, Low, Moderate, Significant, and High). Figure 9.3 illustrates the number of hazard classes used by each state.

9.3.4. Additional Class Distinctions

Since new spillway requirements are often more conservative, upgrading an existing dam to meet current requirements each time the criteria are changed can be costly. For this reason, many states allow a reduction of SDF or even exemption from the updated criteria for dams existing prior to adoption of the criteria. Fifty-one percent of the responding states indicated that their guidelines for new and existing dams differ. The other 49% of the states hold all dams to the same standard, regardless of when they were constructed.

In addition to distinction between new and existing dams, several states require that mine tailings and coal ash dams be held to a different design standard. Fourteen percent of the respondents stated that their guidelines include additional design criteria for such dams.

In Alaska, the protection of anadromous fish habitat has been included in the hazard potential classification system. Missouri specifies varying hazard criteria based on dam type (conventional or industrial), stage of construction, and environmental class.

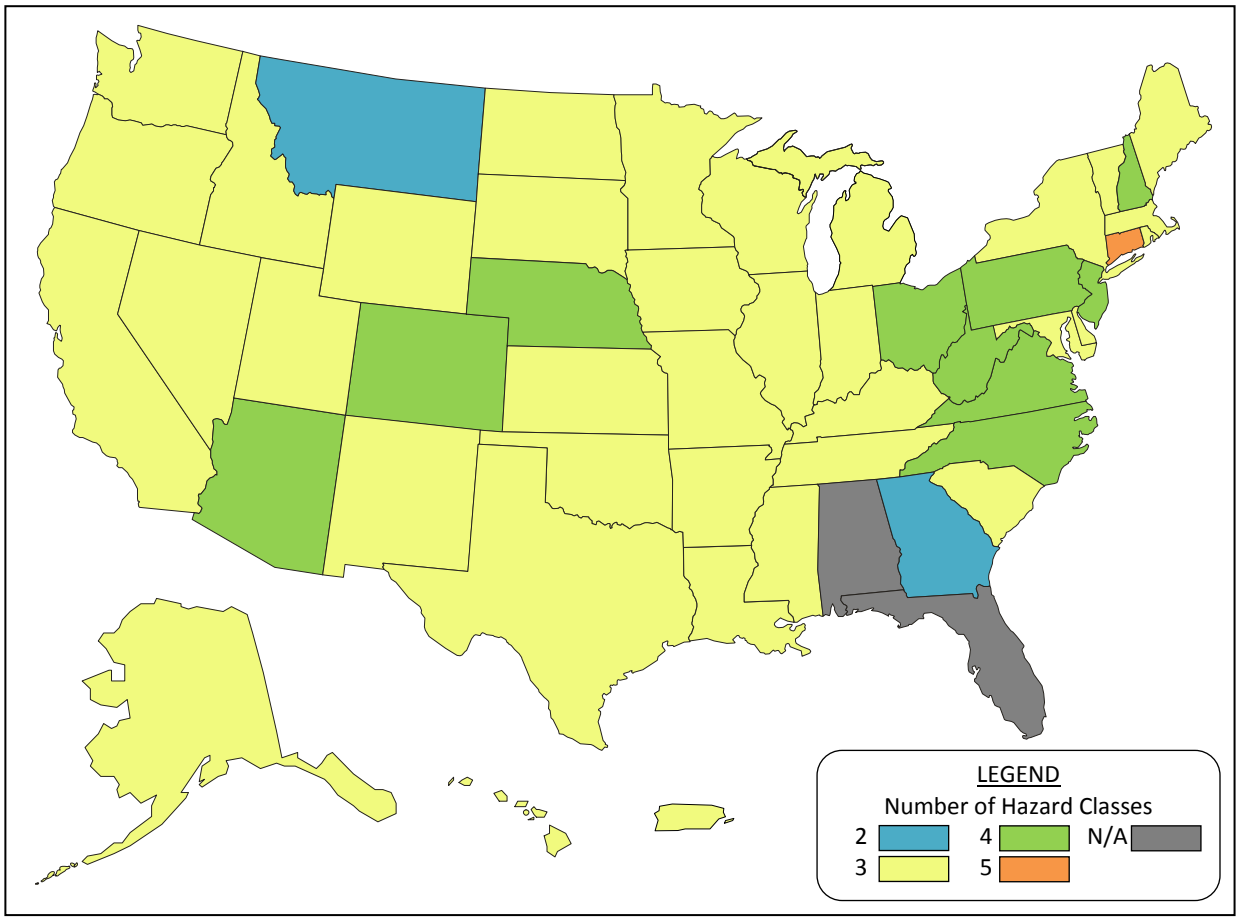


Figure 9.3 Hazard Classification Criteria within the United States and Puerto Rico

9.4. Determining the Spillway Design Flood

In determining the magnitude of the SDF, most states follow a prescriptive approach. Under a prescriptive approach, a design flood would be specified based upon the dam's classification (size, hazard, or both). Of the states using a prescriptive approach for SDF selection, most criteria are based upon either the hazard classification or a combination of size and hazard classifications. Georgia is the only state where the SDF is determined using only size classification criteria. Figure 9.4 shows a summary of each state's current approach to determining the SDF.

In the past few decades, a few states (including California, Washington, and Montana) have developed risked-based spillway design criteria. These methods are typically simpler than a rigorous risk analysis yet more complex than the typical hazard classification system. These criteria often determine the SDF using probabilistic loss of life estimates or consequence rating evaluation. The design flood in a risk-based system is often determined using a sliding scale between some lower threshold flood event and the maximum theoretical event. A few examples of such criteria are discussed in greater depth in Section 9.13 of this chapter.

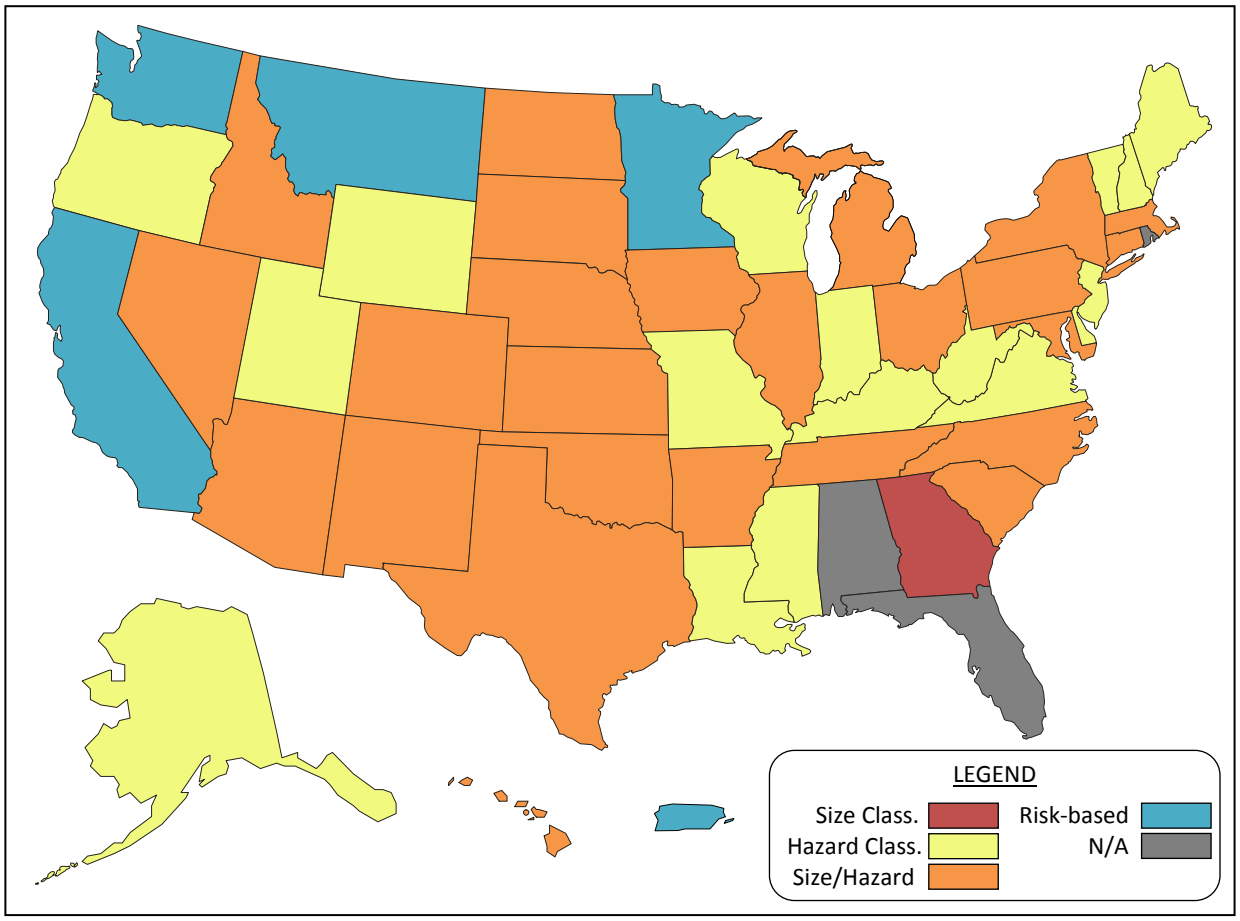


Figure 9.4 Approach to Selecting the SDF within the United States and Puerto Rico

Criteria for determining the SDF can be classified further as either probabilistic or deterministic. Probabilistic criteria are based on either floods or rainfall events which have specified probabilities or return periods. Deterministic criteria are based on PMP estimates or PMF estimates which are a derivative of the PMP. Of the states that utilize a deterministic approach, 33% define criteria with relation to the PMP while 67% are defined with relation to the PMF.

The variance in SDF criteria for new dams is significant as illustrated in Figures 9.5, 9.6, and 9.7. These figures represent the ranges of events specified by each state for low, significant, and high hazard dams. As described previously, there are many differences in the dam classification systems used by various states. In states where a High, Significant, and Low hazard rating system does not apply, classification systems were generalized to allow the comparison of SDF criteria. Also note that although probability events are shown on the figures, their plotted locations are not representative of their magnitude with relation to the probable maximum event. Tables 9-1 thru 9-3 provide additional analysis of spillway design criteria for both new and existing dams.

For new High Hazard dams, nearly half of the responding states indicated that the SDF should be no less than the probable maximum event. Eighty-two percent of the states use criteria extending up to the probable maximum event, usually dependent on size or hazard. A few states require only a fraction of the probable maximum event including Missouri (50 to 75% PMP depending on stage of construction), Colorado (45 to 90% PMP), Kansas (40% PMP), and Michigan (200-year event to 50% PMF). Wisconsin specifies that the SDF for a High Hazard dam is the 1000-year event. Idaho and Alaska specify that a SDF of 100-year magnitude is sufficient in some instances.

For new Significant Hazard dams, the range of SDF criteria is increasingly varied with acceptable design ranges stretching from the full probable maximum event down to the 100-year event. Thirteen states specify 50% of the probable maximum event as the SDF for a significant hazard dam. Several other states use the 50% mark as either an upper or lower limit.

For new Low Hazard dams, 15 states specify the 100-year event for spillway design. Eight additional states specify the 100-year event as a lower design limit. Low hazard spillway design in 11 states extends down to the 50-year flood. North Dakota is the only state allowing the 25-year event as a low hazard design event. For some large, low hazard dams, South Carolina and Tennessee require that the spillway pass the full probable maximum event. California's minimum design event is the 1000-year flood.

In Colorado, the spillway design ranges shown in Figures 9.5 thru 9.7 relate to a standard design using percentage of the PMP as developed using the appropriate HMR. Colorado has also specified SDF criteria for special cases such as high elevation dams and site specific PMP studies. For dams at elevations higher than 5,000 feet above MSL, PMP estimates can be decreased by an additional 5% or more depending on elevation [Colorado DNR, 2007].

In Virginia, the past few years have seen significant changes with regard to the hydrologic safety of dams. In response to revised regulations containing stricter hazard classification criteria, a dam owner recently led an effort to pass legislation that would provide relief to existing dam owners [Zamensky, 2010]. Multiple bills were subsequently passed. Under the new laws, the maximum design storm event to be required of existing dams is 90% of the PMP (formerly 100% of the PMP). Further reduction to 60% of the PMP was also permitted if certain conditions were met. These conditions include performing daily inspections, having an approved Emergency Action Plan, and obtaining insurance in an amount that would cover all losses due to dam failure. With regards to incremental damage analysis, the new laws also reduced the allowable lower limit of the SDF from 50% of the PMF to the 100-year flood [Commonwealth of Virginia, 2010].

Overall, it appears that current state SDF criteria for all dam hazard classes are similar to those reported in 1985 by the NRC. The following observations made in 1985 are equally applicable today:

- "Use of PMP estimates for evaluating spillway capacity requirements for large, high-hazard dams predominates, although a number of state agencies have indicated that their standards do not require that such dams pass the full estimated PMF based on the PMP.

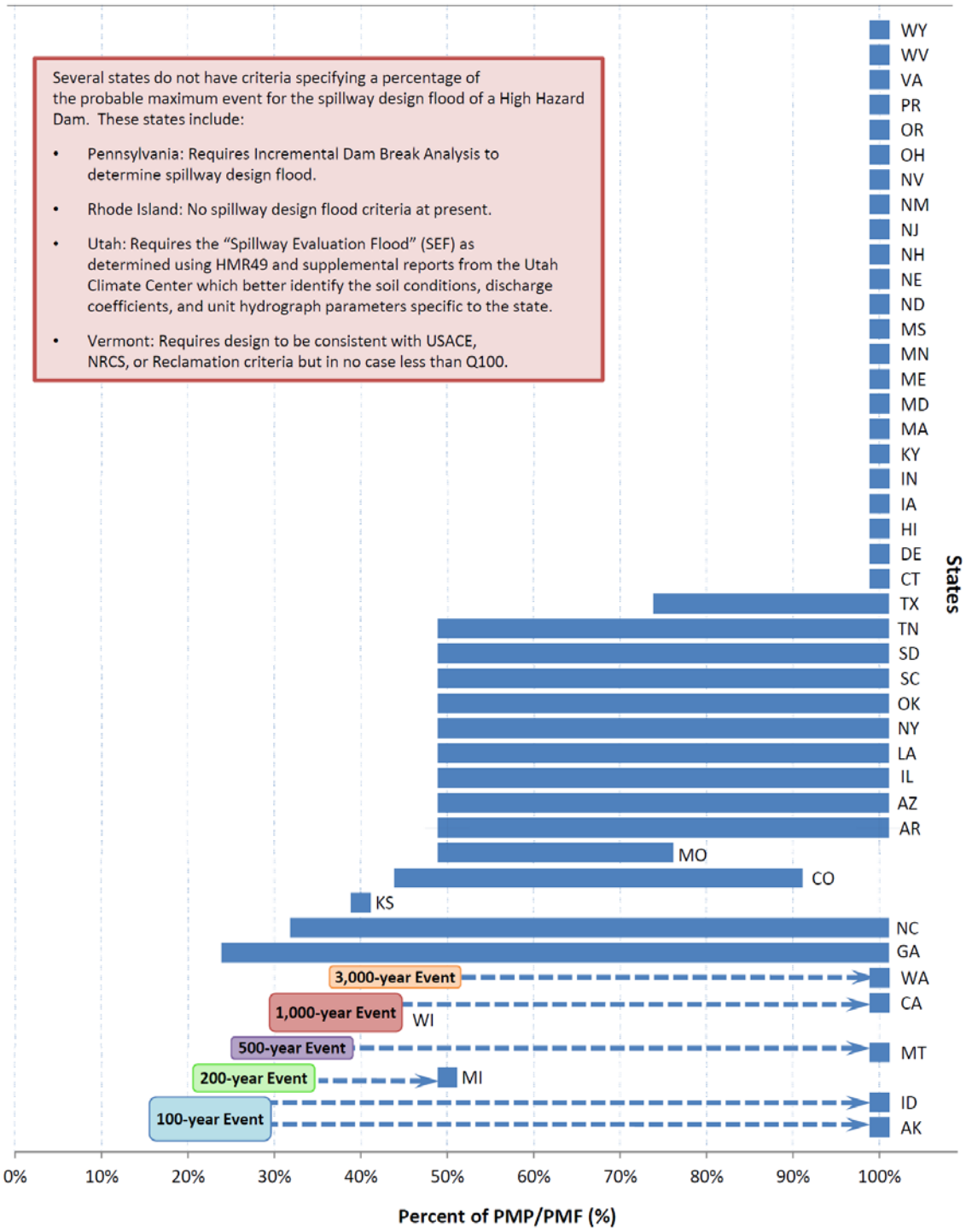
- "The influence of the practices of the principal federal dam-building agencies is evident in the majority of the standards for large, high-hazard dams, but the practices of those agencies have had less effect on current state standards for small dams in less hazardous situations.
- "Apparently as a result of the National Dam Inspection Program for nonfederal dams carried out by the Corps of Engineers in the 1977-1981 period, several state dam safety agencies have adopted the spillway capacity criteria used in those inspections.
- "Several states have adapted the standards used by the Soil Conservation Service (now NRCS) for the design of the tens of thousands of smaller dams constructed under that agency's programs.
- "Current practices include use of arbitrary criteria (such as 150 percent of the 100-year flood, fractions of the PMF, and combinations of the PMF with probability based floods) for which there is no apparent scientific rationale."

Note that the NRC's Committee on Safety Criteria for Dams questioned the use of composite criteria (combining flow frequency concepts with PMF concepts) as well as specifying percentages of the PMP, PMF, or various frequency events. "The problem with such a criterion, based on an arbitrary percentage of a derived flood or an arbitrary combination of floods developed from differing concepts, is that it permits no direct evaluation of the relative degree of safety provided." [NRC, 1985] The issue was further expounded upon in 1988 by the ASCE Task Committee on Spillway Design Flood Selection who stated:

> *"Studies by the National Weather Service indicate that the occurrence of a storm producing PMP is not equally probable nationwide. Thus, using a fraction of the PMF results in selecting a safety design flood which varies widely in exceedance probability… As long as the PMF is used to define a probable upper limit to flooding for use in a safety design, this is not a major concern. The exceedance probability of the PMF, assuming it is correctly defined, is essentially zero. When selecting a safety design flood less than the PMF, use of a fraction of the PMF produces a variation in exceedance probability that results in an inconsistent national safety standard"* [ASCE, 1988].

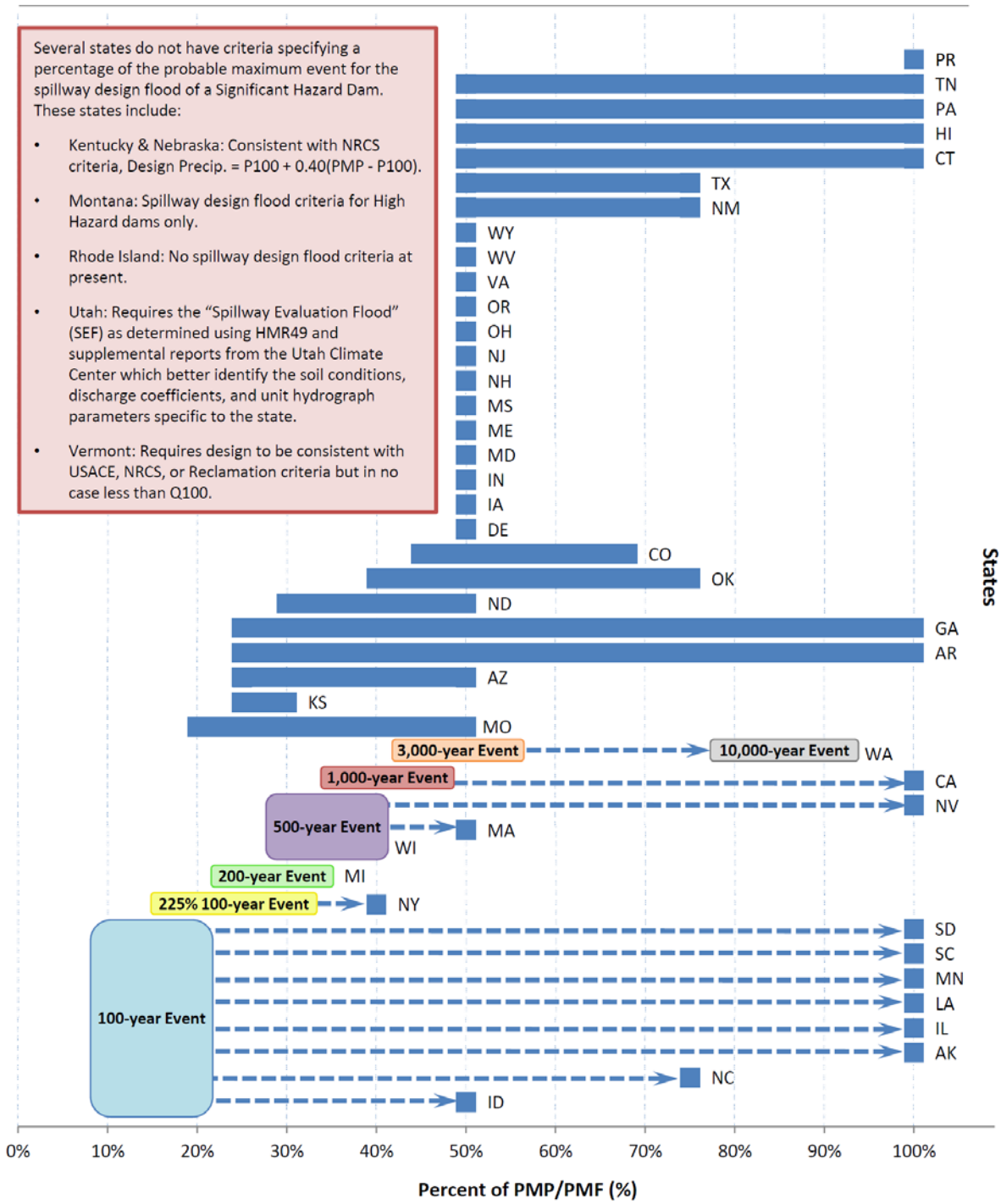
In light of technological advances which aid in calculating and assessing failure consequences, the ASCE Committee continued on to also question the practice of grouping dams based on size except for "projects too small and damages too low to warrant the expense of a specific failure analysis" [ASCE, 1988].

Although these concepts were disputed by experts in the mid- to late-1980s, the majority of state dam safety agencies continue to utilize such criteria multiple decades later. The NRC Committee did recognize that regional differences in climate, geography, and urbanization could justify differences in spillway design criteria. However, they also noted that not all criteria "could be efficient in limiting risks of dam failures to acceptable limits or in protecting the public interest" and recommended that more uniform approaches to specifying spillway capacity be considered.



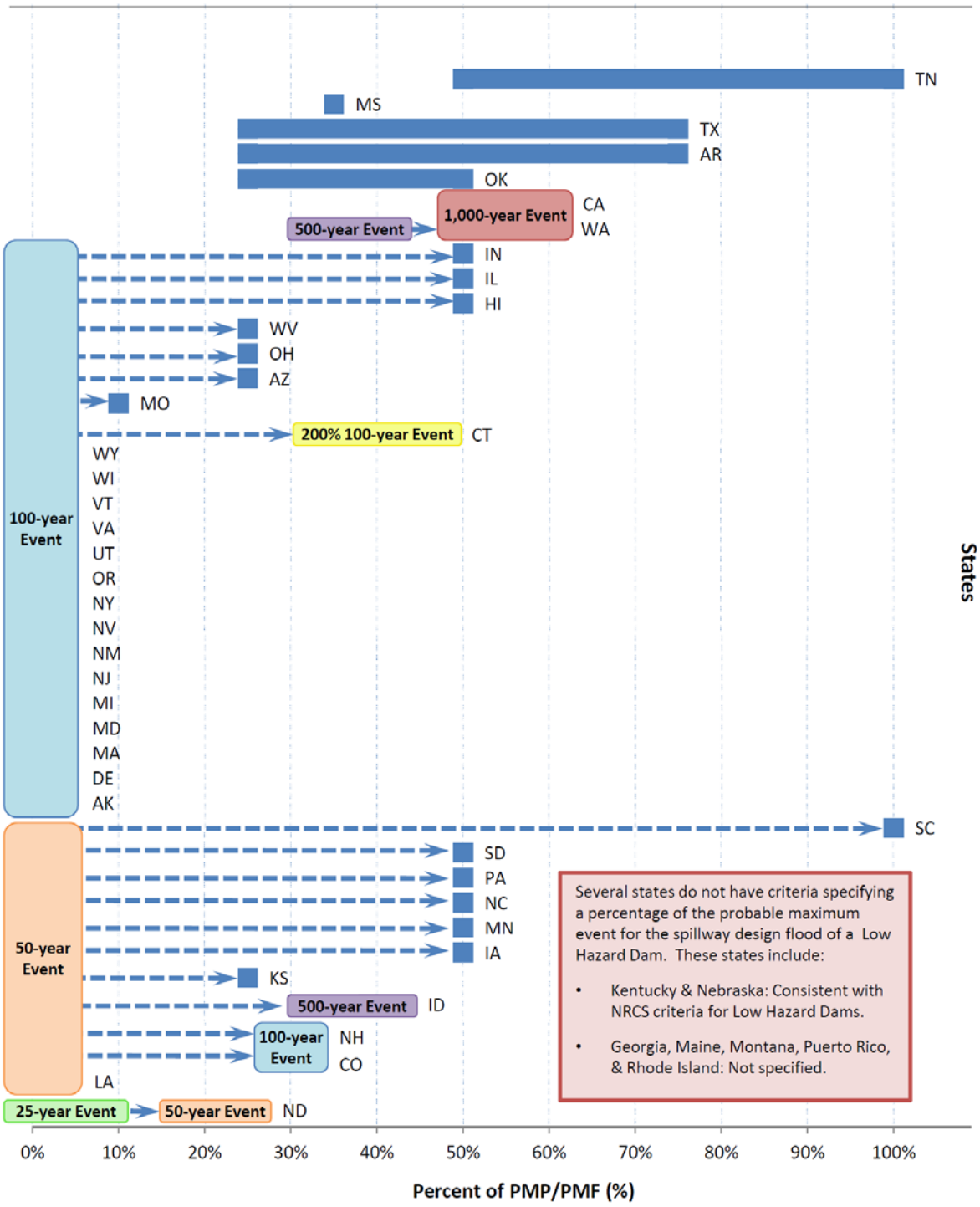
Note: For probability events (such as the 100-year flood), the corresponding percentage of the probable maximum event varies significantly in different areas of the country. The plotted location of probability events do not, therefore, represent the corresponding PMP/PMF percentage.

Figure 9.5 Range of Spillway Design Flood Criteria for New High Hazard Dams



Note: For probability events (such as the 100-year flood), the corresponding percentage of the probable maximum event varies significantly in different areas of the country. The plotted location of probability events do not, therefore, represent the corresponding PMP/PMF percentage.

Figure 9.6 Range of Spillway Design Flood Criteria for New Significant Hazard Dams



Note: For probability events (such as the 100-year flood), the corresponding percentage of the probable maximum event varies significantly in different areas of the country. The plotted location of probability events do not, therefore, represent the corresponding PMP/PMF percentage.

Figure 9.7 Range of Spillway Design Flood Criteria for New Low Hazard Dams

Table 9-1 Spillway Design Flood Criteria for New and Existing High Hazard Dams

Spillway Design Criteria	Number of States Specifying Criteria for New Dams	Number of States Specifying Criteria for Existing Dams
Requiring a Max Less Than 100% PMF	4	9
Requiring up to 100% PMF	17	15
Requiring Exactly 100% PMF	23	19
Requiring Incremental Damage Analysis	1	1
No Answer/Other*	4	5

**Includes 1,000-year event as well as recommendations to use various federal criteria.*

Table 9-2 Spillway Design Flood Criteria for New and Existing Significant Hazard Dams

Spillway Design Criteria	Number of States Specifying Criteria for New Dams	Number of States Specifying Criteria for Existing Dams
Requiring a Max up to 50% PMF	7	7
Requiring Exactly 50% PMF	13	13
Requiring Maximum between 50% PMF and 100% PMF	19	17
No Answer/Other*	10	12

**Includes 200-year event, 500-year event, 150% 100-year event, 25% PMP, 30% PMP, 40% PMP, and recommendations to use specific federal criteria.*

Table 9-3 Spillway Design Flood Criteria for New Low Hazard Dams

Spillway Design Criteria	Number of States Specifying Criteria for New Dams
Requiring Exactly 100-year Event	15
Requiring up to 100-year Event	2
Requiring up to 25% PMF	4
Requiring up to 50% PMF	9
Requiring up to 75% PMF	2
Requiring up to 100% PMF	2
Other*	9
Not Specified	6

**Includes 25-year event, 50-year event, 200% 100-year Event, 500-year event, 1000-year event, 10% PMP, 35% PMP, and NRCS criteria for low hazard dams.*

9.5. Storm Duration and Distribution

Thirty-seven percent of the states do not specify design storm duration within their hydrologic design guidelines. Of the 63% that do provide specific guidance regarding storm duration, it is typical to base the duration on the watershed's time of concentration or consider durations ranging from 6 hours to 72 hours. It should be noted that time of concentration is not the only determining factor in selecting the appropriate storm duration. For example, a reservoir with a large amount of available storage may not be significantly impacted by a short duration storm. A longer duration event yielding a larger volume of runoff could, therefore, govern the hydrologic design. Caution should be used when applying limiting or specific design criteria. Such criteria should allow for deference to a competent design engineer. The respondent in Alaska noted that hydrologic design criteria have specifically been excluded from their regulations to allow engineers to develop reasonable designs.

For the temporal distribution of the design storm, 57% of the states do not provide guidance. Of the 43% that do define the temporal distribution, about half indicate that the HMRs published by the National Weather Service should be used. Other commonly used temporal distributions include those developed by the NRCS as well as regional or custom distributions developed by the states.

One respondent noted that the duration and temporal distribution of a rainfall design event can have considerable impact on the required hydrologic design of a dam. Prior to 2005, the NRCS 6-hour design storm distribution was the basis for design of NRCS dams. The 6-hour rainfall amount and storm distribution has been used by the NRCS for over 50 years to set the top of dam and spillway requirements and is well established. Longer storm durations were considered only if the time of concentration exceeded six hours or the contributing drainage area exceeded 100 square miles. For dams with contributing drainage areas exceeding 100 square miles, the NRCS recommended that individual watershed PMP studies be performed by the NWS to take into account orographic features that are smoothed in the generalized precipitation studies.

In 2005, the NRCS revised TR-60 to require the analysis of both the 6-hour and 24-hour duration with the most critical results used for checking the discharge capacity and the integrity of the auxiliary spillway. It should be noted that although the 6- and 24-hour PMP rainfall amounts are obtained from NWS Hydrometeorological Reports, the rainfall distributions presented in TR-60 are used by the NRCS rather than the rainfall distributions presented in the hydrometeorological reports. For example, in the eastern United States, the rainfall distribution for the 24-hour duration PMP storm is not the same "critically stacked" rainfall distribution obtained using HMR-52, as it does not include critically stacking shorter duration rainfalls within the peak 6-hour rainfall. The NRCS approach to constructing the 24-hour storm is to critically stack incremental rainfall amounts of successive 6-, 12- and 24-hour durations, but distributing each 6-hour PMP depth uniformly over each six-hour period. This distribution is referred to by the NRCS as the 5-point storm distribution. The aforementioned 24-hour rainfall distribution was adopted primarily for checking the integrity

of the auxiliary spillway since it produces a greater runoff volume and longer spillway flows as compared to the 6-hour PMP storm.

A comprehensive discussion of temporal rainfall distributions for near PMP storm events for design of NRCS dams is presented in a paper by James N. Moore et al. (2001). Based on an evaluation 72 NRCS dams, use of the 24-hour 5-point rainfall distribution would require 54 percent of the dam heights to increase with 61 percent within plus or minus one foot of the 6-hour design criteria. The HMR-52 rainfall distribution would require 97 percent of the dam heights to increase with 47 percent within plus or minus one foot of the 6-hour design criteria.

Montana and Washington have developed regional precipitation-frequency analyses to determine the return period of extreme events [Fischer & Lemieux, 2010; MGS Engineering Consultants, Inc., 2009]. Nebraska has had a site-specific PMP study performed for the entire state which resulted in PMP reductions ranging from 3 to 56 percent [Applied Weather Associates, 2008].

The majority of states do not provide guidance regarding the spatial distribution of a storm. The few states that do include it in their guidelines indicate that spatial distribution should only be used in cases where the drainage area is greater than 10 square miles.

9.6. Antecedent Moisture Conditions and Initial Reservoir Pool Levels

In developing the SDF and designing the dam, initial assumptions such as antecedent moisture conditions (AMC) and the initial reservoir pool level can have a significant impact on the results. Twenty-nine of the forty-nine states (59%) surveyed do not specify or provide direction regarding either of these variables in their guidelines. Of the states that do specify antecedent moisture conditions, most use either SCS AMC-II or AMC-III criteria. Several states also have specific directives regarding the consideration of snowmelt and frozen ground conditions.

For initial reservoir pool level criteria, most states specify that normal water surface elevation be used as an initial routing condition. Others specify similar criteria such as the “lowest uncontrolled spillway inlet” or “at the crest of the spillway for permanent water storage.”

9.7. Freeboard Requirements

For a PMP/PMF design, 37% of the surveyed states do not require freeboard above the peak PMP/PMF reservoir level. The remaining states use many varying criteria based on dam type, wave run-up calculations, dam size or hazard classification, and case-by-case evaluations. The following comments from survey respondents illustrate several of these varying criteria:

- Oklahoma – “Minimum freeboard varies from 1 to 3 feet based on both hazard and size classification.”

- Illinois – Freeboard is determined on a "case-by-case basis considering many factors including duration of high water levels during the design flood, the effective wind fetch and reservoir depth available to support wave generation, the probability of high wind speed occurring from a critical direction, the potential wave run up based on roughness and slope, and the ability of the dam to resist erosion from overtopping waves."
- Iowa – "For dams with emergency spillways, the top of dam elevation after settlement shall not be less than the highest peak pool elevation reached during the freeboard design flood. For dams without an emergency spillway, the top of dam elevation shall be 2 feet higher than the peak flood elevation expected to occur during passage of the freeboard design flood, unless it is specifically designed to withstand the overflow."
- Nevada – "'Rule of thumb' is 3 feet. Wave run up calculations are preferred and required if the owner is requesting a smaller freeboard. Exceptions are tailings facilities for deposition (beach) side embankments and Storm Water detention facilities."
- Colorado – "The minimum freeboard requirements for new or enlarged dams shall be based upon the dam height required to prevent overtopping by wave action, or the sum of the IDF maximum water surface level plus 1 foot of residual freeboard, but not less than 5 feet unless the State Engineer approves a lesser amount. Except for concrete dams where the design engineer has demonstrated that overtopping of the dam will not be detrimental to the safety of the dam, the IDF can be accommodated with zero residual freeboard or the overtopping depth at which the dam still meets the stability and stress requirements of Rule 5.9.5."
- Georgia – Based on wave run up computations with a "3-foot maximum."
- New York – "One foot minimum for small dam, 2 foot minimum for large dam."

This sampling of criteria as well as the large percentage of states that do not require freeboard demonstrates the variation that exists in current freeboard criteria. It is also apparent that there is a significant variation in the level of detail required for freeboard analysis among the states.

9.8. Applicable Methodologies and Software

The majority of state agencies will allow the use of any analysis methodologies, procedures, or computer software as long as results are verifiable and applied using good engineering practice. There are, however, several states which stipulate a specific methodology (i.e. using HMRs to develop the PMP) or approved computer software (i.e. HEC applications, NWS DAMBRK, SITES, etc.). The states of Mississippi, New York, and Pennsylvania specifically do not allow the use of the rational method in any case.

9.9. Provisions for Future Development

One common issue faced by regulatory agencies is development both upstream and downstream of existing dams. Development within a watershed can cause increased runoff and peak inflows higher than those used to design a dam. In some cases, development extends into the flood pool of a structure which poses a risk to those developments.

The development of an area downstream of a dam often causes a condition called "hazard creep." Low or significant hazard dams which are oftentimes built in rural areas are reclassified as high hazard dams due to development that occurs after construction of the dam. These reclassified dams are then subject to increasingly conservative design standards and usually need to be upgraded to pass flood events of a greater magnitude.

Figure 9.8 illustrates the percentage of states that specifically require consideration of future development when determining the SDF. Note that 22 states (45%) do not require the designer to consider upstream or downstream development when designing a dam, and only 6 states (12%) require the consideration of development upstream of the dam. Sixty-nine percent of states surveyed felt that hazard creep due to development was a problem, though only twelve percent considered it a major problem.

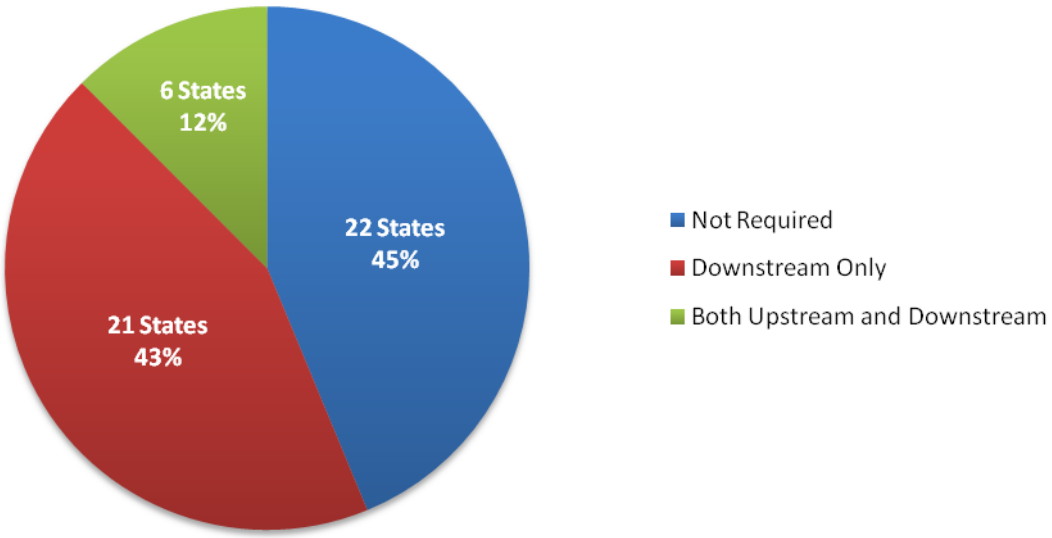


Figure 9.8 Consideration of Future Development for Spillway Design Flood Criteria

In Illinois, Delaware, and New Jersey, all Low and Significant Hazard dams must incorporate alternatives in the proposed design for increasing the total spillway capacity if the downstream hazard potential increases. Future downstream land use, land use controls, and growth projections are considered in the review of the spillway capacity design.

9.10. Early Warning Systems

When asked if an early warning system would be considered as an alternative to designing a high hazard dam for the regulatory SDF, the majority of states indicated that such an alternative would not be acceptable. Many noted that a safe design should be passive and not require significant maintenance or operation. Of the 10 states that would consider this as a viable alternative, most

required significant justification and additional protective measures to be included with the early warning system. Most of these agencies would only consider this as an alternative for existing dams or as a temporary solution until structural modifications are made.

In 1995, Dubler asked state dam safety officials a similar question and found that about 15 states would allow the use of an early warning system on a case-by-case basis. This indicates a slight trend away from the use of these systems over the past 15 years.

9.11. Incremental Damage Analysis

As described in Chapter 3, incremental damage analysis is a comparative hazard approach that creates a compromise between the desire to provide a risk-based analysis of the benefits gained from mitigating the hazard and the traditional approach of requiring a design capable of safely passing the PMF. Of the responding states, 67% indicated that they allow the use of incremental damage analysis to establish the SDF (See Figure 9.9). A few allowed this type of analysis only in evaluating existing dams. Of those who allow incremental damage analysis, less than half require that future downstream conditions within the dam failure inundation zone be considered in the incremental damage analysis.

It is interesting to note that in the survey performed in 2003 by Paxson and Harrison, 88% of survey participants responded that their state would allow incremental damage analysis as opposed to 65% in 2011. The reason for this discrepancy is unknown; however, the 2011 response seems to correspond more closely to Dubler's 1995 survey in which 59% of respondents indicated that incremental damage analysis was utilized. In any case, it appears that the use of incremental damage analyses has become more common in the past decade.

Since incremental damage analysis is typically used to decrease the SDF, some states place a minimum limit on the SDF regardless of downstream consequences. Eighteen states indicated that they have restrictions or guidelines on the use of incremental damage assessments or risk analyses. Table 9-4 summarizes most of these criteria.

While most states perform incremental damage analysis in the downstream dam failure inundation zone to establish the magnitude of the SDF, some have also applied the concept to the mitigation of flooding due to spillway discharge. This would apply in situations where gate operators or fuse plugs provide the dam owner some control over spillway discharge. In Arizona, spillways are required to be constructed in a manner that avoids flooding in excess of that which would have occurred under the same conditions before construction. Other states have expressed similar interest in regulating flooding due to spillway discharge.

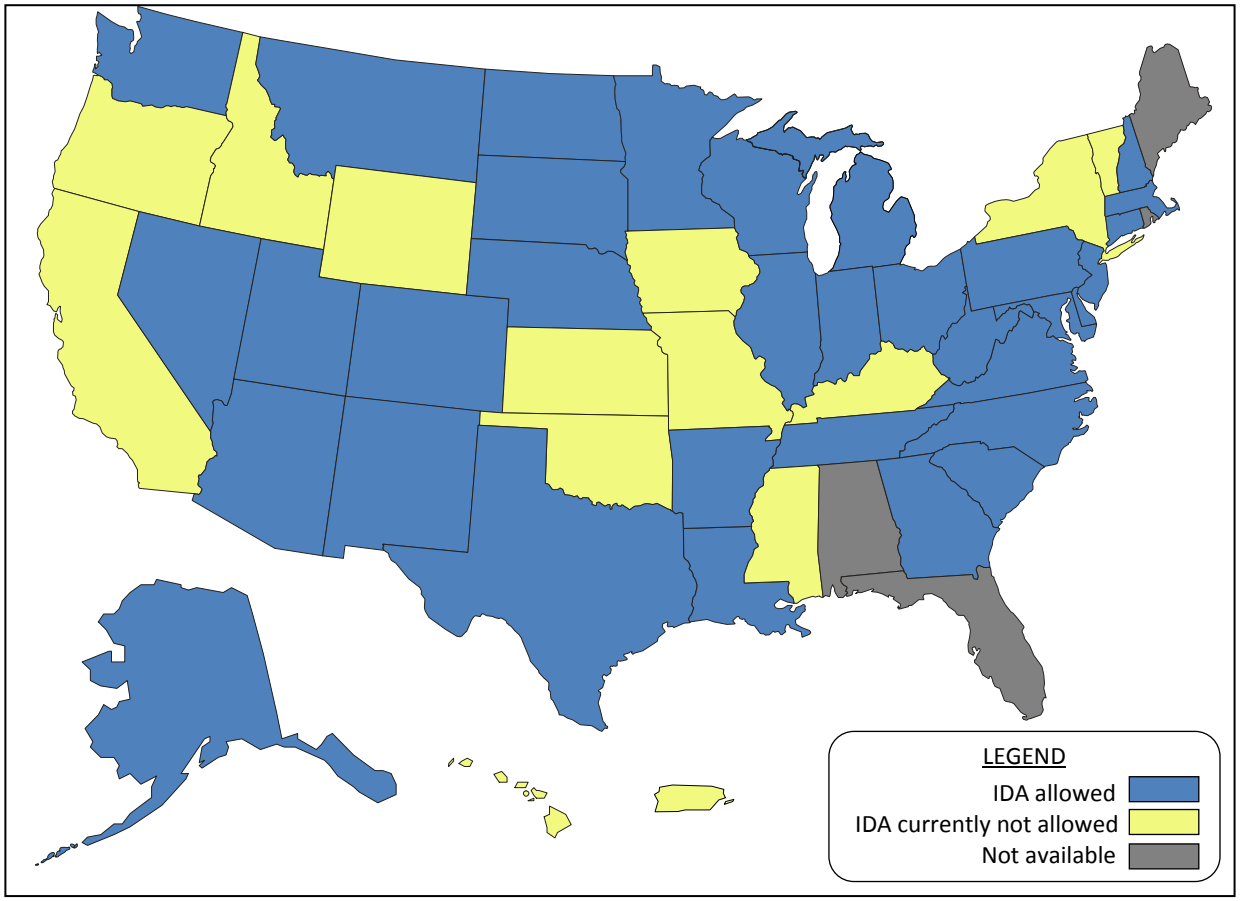


Figure 9.9 Use of Incremental Damage Analysis in the United States and Puerto Rico

Table 9-4 Minimum Design Event when Incremental Damage Analysis is Applied

Criteria	States Using this Criteria
Minimum SDF: 100-year flood (High and Significant Hazards); 50-year Flood (Low Hazard)	VA
Minimum SDF: 100-year frequency flood or storm event	AK, CO, DE, IL, NC, NJ, NM, NV, PA, SD, UT
Minimum SDF: 200-year flood or flood of record, whichever is greater	MI
Minimum SDF: 40% PMF (High Hazard); 20% PMF (Significant Hazard); 100-year flood (Low Hazard)	OH
Minimum SDF: 50% PMP (High Hazard); 100-year flood (Low Hazard)	IN
Minimum SDF: 70% PMP (High Hazard); 25% PMP (Significant Hazard); P100 (Low Hazard)	WV
SDF can only be reduced by up to 10%	GA

9.12. Provisions for Developing Site Specific PMP

The practice of developing a site specific PMP for a dam design is allowed in 32 states (65%). It is restricted in 6 states (12%). Permission to perform a site specific study in the remaining 11 states (22%) has never been requested (See Figure 9.10). It is important to note that of the 32 states allowing site specific PMP studies, more than half (17 states) have no guidelines, requirements, or restrictions regarding this practice.

Those that do have guidelines, requirements, or restrictions utilize a variety of criteria. Several states require a site specific design to pass through special levels of review or even be overseen by a board of consultants. Mississippi will only consider a site specific study if the drainage area is greater than 10 square miles. New Jersey only allows the use of site specific PMP's for existing structures. Colorado has a completely separate requirements matrix for site specific analyses. Using this guideline, a dam is required to pass a higher percentage of the site specific PMP/PMF than is required if the SDF has been developed following the HMR approach.

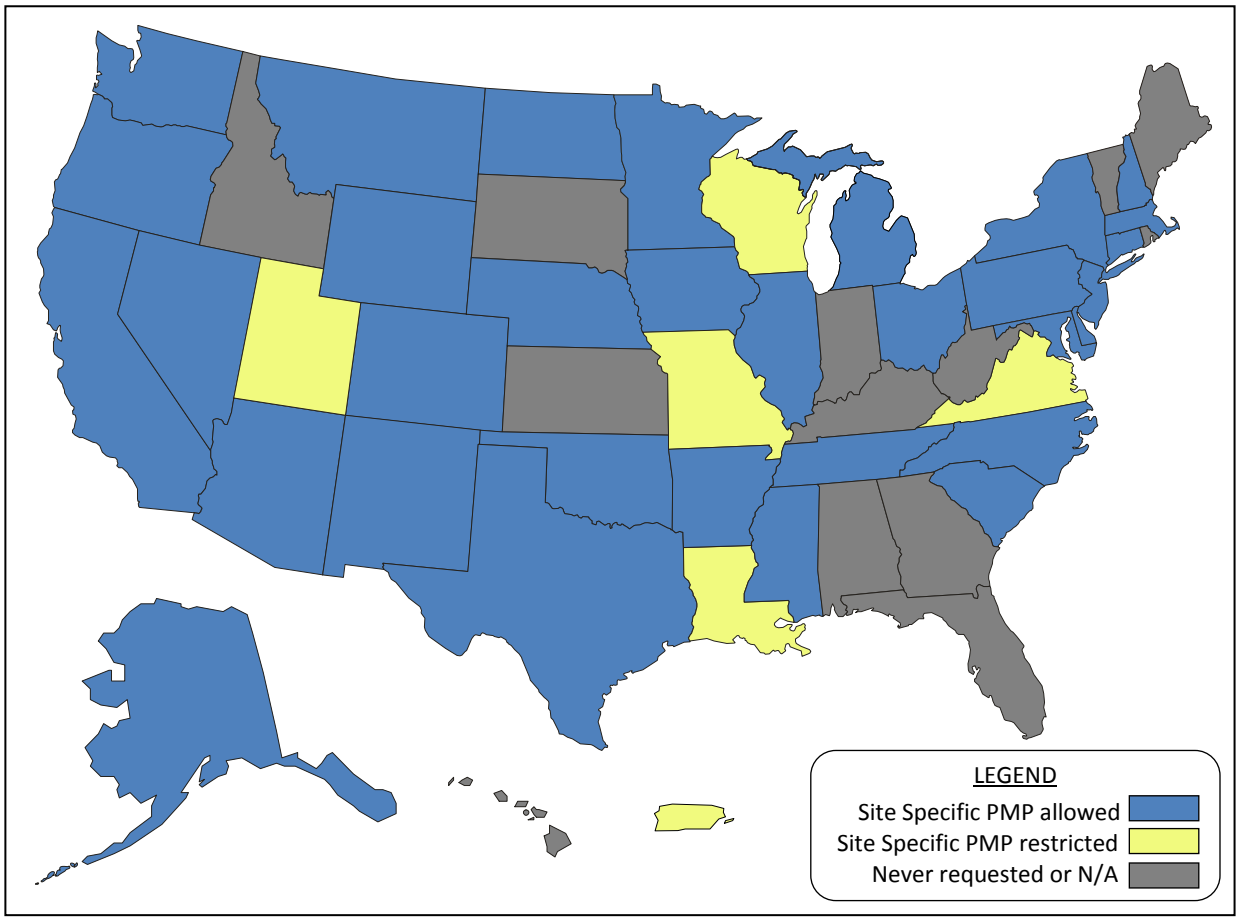


Figure 9.10 Use of Site Specific PMP Studies in the United States and Puerto Rico

9.13. Risk-based Criteria

Within the 1988 report published by ASCE, the Task Committee on Spillway Design Flood Selection concluded that the only standard which "could be applied consistently both today and in the future would be a selection based upon a site-specific evaluation of the likelihood of failure and the social, economic, and environmental consequences of failure – a quantitative risk assessment. A quantitative risk assessment provides the decision maker at each level of the decision making process – the engineer, the dam owner, and the regulator – with the information needed to select a safety design flood" [ASCE, 1988]. States tend to look toward the federal agencies to initiate changes in regulations, and the majority of federal agencies have made policy shifts toward the use of risk analysis (See Chapter 8). The level of acceptance continues to be greatly varied. It appears that the Bureau of Reclamation has fully embraced the use of quantitative risk analysis for the hydrologic design of dams. Several other state and federal agencies are taking a more gradual approach to adopting risk-based designs. In these agencies, the use of incremental damage analysis is a common way to introduce components of risk analysis into design criteria. It should be noted that the establishment of any guidelines introduces some sort of risk assessment. States that currently base dam design standards on size or hazard classification systems are effectively performing very generalized and informal risk analysis.

9.13.1. Current Use of Risk-based Criteria by the States

Of the 49 states surveyed, 15 (31%) indicated that they permit or review risk-based designs. Seven states (14%) indicated that risk-based designs are either forbidden by regulation or will not be considered due to administrative decision. The remaining 27 states (55%) indicated that their regulations do not specifically address the topic of risk analysis and it has never come up for consideration.

The same question regarding risk-based hydrologic designs was asked in Dubler's survey. In 1995, 43% indicated that they either permitted or reviewed risk-based designs on a case-by-case basis. The 2003 survey by Paxson and Harrison also indicated that 43% of states would allow the use of risk-based analysis. This decrease indicates that over the past decade, a number of states have stopped allowing the use of risk analysis. Chapter 10 provides a discussion of several trends which may have caused this reduction in the allowance of risk analysis.

In contrast to the current trend, a few states have dedicated significant resources over the past 30 years to develop risk-based design criteria for dams. Generally speaking, these risk-based guidelines do not comprise rigorous or quantitative risk analysis. Rather, they incorporate both principles of risk with some sort of hazard classification or consequence rating system. The design flood in a risk-based system is often determined using a sliding scale between a lower threshold flood event and the maximum theoretical event. California, Washington, and Montana each have unique risk-based criteria for the hydrologic design of dams.

9.13.2. California

In 1981, the State of California became the first state to adopt a risk-based methodology that could be applied to any spillway in the state [Calzascia & Fitzpatrick, 1987]. One challenge of devising such a method is that it must be able to be applied both rationally and consistently across a broad range of dam types and sizes. Under this methodology, a dam's hazard classification is determined by considering reservoir capacity, dam height, estimated number of people evacuated in anticipation of failure, and potential downstream damage.

> *"Each factor is categorized as low, moderate, high or extreme. The method produces a composite numerical rating termed the Total Class Weight (TCW)… With this system, small remote dams generally have a TCW of 2, while large urban dams might have a TCW of 36. The capacity of the reservoir and height of the dam are clearly defined. Estimated evacuation and potential downstream damage are uncertain and require an investigation of the potentially flooded area. This investigation includes estimating the population at risk, the possible loss of life, the physical property damage, the social consequences and the environmental impact. Through application to the many dams under its jurisdiction, [California's Division of Safety of Dams] has developed a coherent and uniform approach to conducting the damage investigations so that consistent total class weights are found"* [Calzascia & Fitzpatrick, 1987].

Figure 9.11 illustrates the weighting system used in California to determine the TCW. California considers the TCW criteria as an adequate assessment of risk; therefore, they do not allow the use of quantitative risk analysis. Once the TCW has been determined, the appropriate design storm is selected.

> *"The minimum allowable design event required is a 1000 year storm which corresponds with a TCW of 4. The maximum event is a storm derived from the Probable Maximum Precipitation and is equated with a TCW of 30. The design event is interpolated between these limits at the computed TCW"* [Calzascia & Fitzpatrick, 1987].

By applying these risk-based criteria, less than 8% of California's dams are required to pass the full PMF [Calzascia & Fitzpatrick, 1987].

DAMAGE POTENTIAL CLASSIFICATION FOR

FLOOD ESTIMATE AND SPILLWAY ANALYSIS

Name of Dam _____ Type of Dam _____Dam No. _____

County _____ Located on _____

Damage Potential Rating

	Extreme	High	Moderate	Low
Capacity _____ AF	100,000 & Over	1,000-99,999	100-999	15-99
(circle weight)	6	4	2	0
Height _____ Ft.	150 & Over	100-149	50-99	6-49
(circle weight)	6	4	2	0
Estimated Evacuation _____	1,000 & Over	100-999	1-99	None
(circle weight)	12	8	4	0
Potential D/S Damage	High	Moderate	Low	None
(circle weight)	12	8	4	0

Total Class Weight _____

Figure 9.11 Total Class Weight and Hazard Potential Classification in California [Calzascia & Fitzpatrick, 1987]

9.13.3. Washington

In 1990, Washington State adopted an approach to dam safety that "can be characterized as employing risk concepts in a standards-based framework" [Johnson, 2000]. The state's approach utilizes what it calls the "Design Step Format." Under this format, a range of failure consequences are divided into 8 steps. For Design Step 1, the annual exceedance probability of the design event is 1 in 500. This step would apply "when the downstream consequences of a dam failure would be minimal and there would be no potential for loss of life" [Washington State Department of Ecology, 1993]. In situations where the consequences of failure would be "catastrophic," the theoretical maximum design event (PMP/PMF) is applied under Design Step 8. This maximum theoretical event is assumed to have an annual exceedance probability of 10^{-6}. In order to utilize probability-based hydrologic events, Washington has performed regional precipitation-frequency analyses to determine the return period of extreme events.

Table 9-5 outlines the range of consequence rating points assigned to several hazard indicating parameters. Using a cumulative total of consequence rating points, the designer can determine both the design step and the required annual exceedance probability for design as shown in Figure 9.12. This annual exceedance probability will apply to all aspects of the dam design (hydrologic, seismic, etc.) in an effort to provide "balanced protection." Table 9-6 relates the Washington State's design step criteria to typical downstream hazard classifications.

By adopting this approach to dam safety, the state has been able to apply risk concepts in a format that is fairly simple and easy to use. A similar ranking system has been applied to evaluate existing dams, thus allowing a prioritization of compliance efforts. "Of the 46 dams inspected under the National Dam Inspection Program still listed as unsafe in 1990, 40 had been repaired by 1999 [under this standard]. In addition, 78 of the 101 additional dams identified by the state dam safety program since 1985 have been repaired" [Johnson, 2000].

Table 9-5 Numerical Rating Format for Additive Weighting Scheme for Assessing Consequences of Dam Failure [Adapted from Washington Department of Ecology, 1993]

Consequence Categories	Consequence Rating Points	Indicator Parameter	Considerations
CAPITAL VALUE OF PROJECT	0 – 150	DAM HEIGHT	Capital Value of Dam
	0 – 75	PROJECT BENEFITS	Revenue Generation or Value of Reservoir Contents
POTENTIAL FOR LOSS OF LIFE	0 – 75	CATASTROPHIC INDEX	Ratio of Dam Breach Peak Discharge to 100-Year Flood
	0 – 300	POPULATION AT RISK	Population at Risk Potential for Future Development
	0 – 100	ADEQUACY OF WARNING	Likely Adequacy of Warning in Event of Dam Failure
POTENTIAL FOR PROPERTY DAMAGE	0 – 250	ITEMS DAMAGED	Residential and Commercial Property
		OR	Roads, Bridges, Transportation Facilities
		SERVICES	Lifeline Facilities Community Services
		DISRUPTED	Environmental Degradation from Reservoir Contents (Tailings/Wastes/etc.)

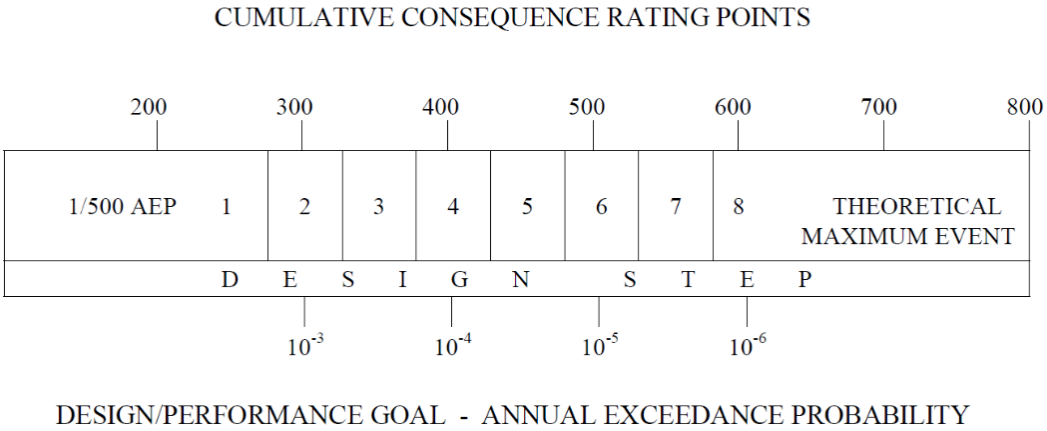


Figure 9.12 Design Step Format and Consequence Rating Points [Washington Department of Ecology, 1993]

Table 9-6 Relationship of Design Step to Downstream Hazard Classification [Adapted from Washington Department of Ecology, 1993]

Downstream Hazard Potential	Downstream Hazard Classification	Population at Risk	Economic Loss	Environmental Damages	Typical Design Step
LOW	3	0	Minimal: No inhabited structures; Limited agriculture development.	No deleterious materials in reservoir	1 – 2
SIGNIFICANT	2	1 to 6	Appreciable: 1 or 2 inhabited structures; Notable agriculture or work sites; Secondary highway and/or rail lines.	Limited water quality: Degradation from reservoir contents and only short term consequences	3 – 4
HIGH	1C	7 to 30	Major: 3 to 10 inhabited structures; Low density suburban area with some industry and work sites; Primary highways and rail lines.	Severe water quality: Degradation potential from reservoir contents and long term effects on aquatic and human life	3 – 6
HIGH	1B	31 to 300	Extreme: 11 to 100 inhabited structures; Medium density suburban or urban area with associated industry; property and transportation features.		4 – 8
HIGH	1A	More than 300	Extreme: More than 100 inhabited structures; Highly developed, densely populated suburban or urban area with associated industry, property, transportation, and community life line features.		8

9.13.4. Montana

Prior to 1999, Montana's Dam Safety Rules established spillway design criteria based on dam height and storage. After recognizing that the required spillway capacity was disproportionate to the level of downstream development, the state developed new hydrologic design criteria based upon estimated loss of life (LOL). Similar to Washington State, Montana has performed regional precipitation-frequency analyses to determine the return period of precipitation events having recurrence intervals up to 5,000 years [Fischer & Lemieux, 2010].

LOL estimates are obtained by considering three factors: 1) PAR or population occupying the area inundated by a dam failure flood, 2) the warning time given to PAR exposed to the resultant flood wave, and 3) the severity of the flood. In general, LOL is significantly less than PAR. The Montana DCNR publication titled "Technical Note 2, Loss of Life Determination for Spillway Capacity Analysis" describes in detail how to calculate LOL.

> *"If the estimated LOL is equal to or less than 0.5, the minimum IDF is the 500-year recurrence interval… If the LOL is greater than 0.5 and less than or equal to 5, the minimum IDF recurrence interval is determined by multiplying the LOL by 1,000* (i.e. a dam with estimated LOL of 2 would be required to pass the 2,000-year flood event)… *If the LOL is greater than 5 and less than 1,000, the precipitation depth for determining the IDF is calculated with equations that effectively interpolate between depths for the 5,000-year storm and the PMP... The IDF for an LOL greater than or equal to 1,000 is the probable maximum flood, or PMF. The PMF is runoff produced by the PMP"* [Hydrometrics, Inc., 2008].

Montana's SDF determination process is illustrated by a flowchart in Figure 9.13.

9.13.5. Inconsistencies with Current Risk-Based Criteria

Within the past few decades, the use of risk analysis and risk-based design criteria has increased. The methodologies developed by California, Washington, and Montana reflect a growing desire for site-specific, cost-effective, and risk-based designs. They also demonstrate how the complexities of risk analysis can be applied in a simplified, standard-based system. Due to a lack of resources and staff in many state dam safety offices, such simplification would likely be necessary if broad application were to be successful. There is also a general lack of region-specific precipitation-frequency analyses, thus making it difficult for states desiring to adopt risk-based criteria to assign annual exceedance probabilities to extreme events.

Perhaps the most apparent observation regarding these recently developed, risk-based approaches is the lack of both consistency between the states as well as defensible risk tolerance criteria. California's weighting criteria are based entirely on the storage volume and height of the dam, the estimated evacuation, and potential downstream damage. Washington's consequence rating points are determined based on similar criteria (capital value of project, potential for loss of life, potential for property damage); however, in Washington's system, loss of life accounts for 50% of the entire

design weight while it accounts for only 33% of the total weight in California. Montana alternatively bases the design entirely (100%) on potential loss of life and completely disregards the value or size of the project as well as potential property damage due to dam failure.

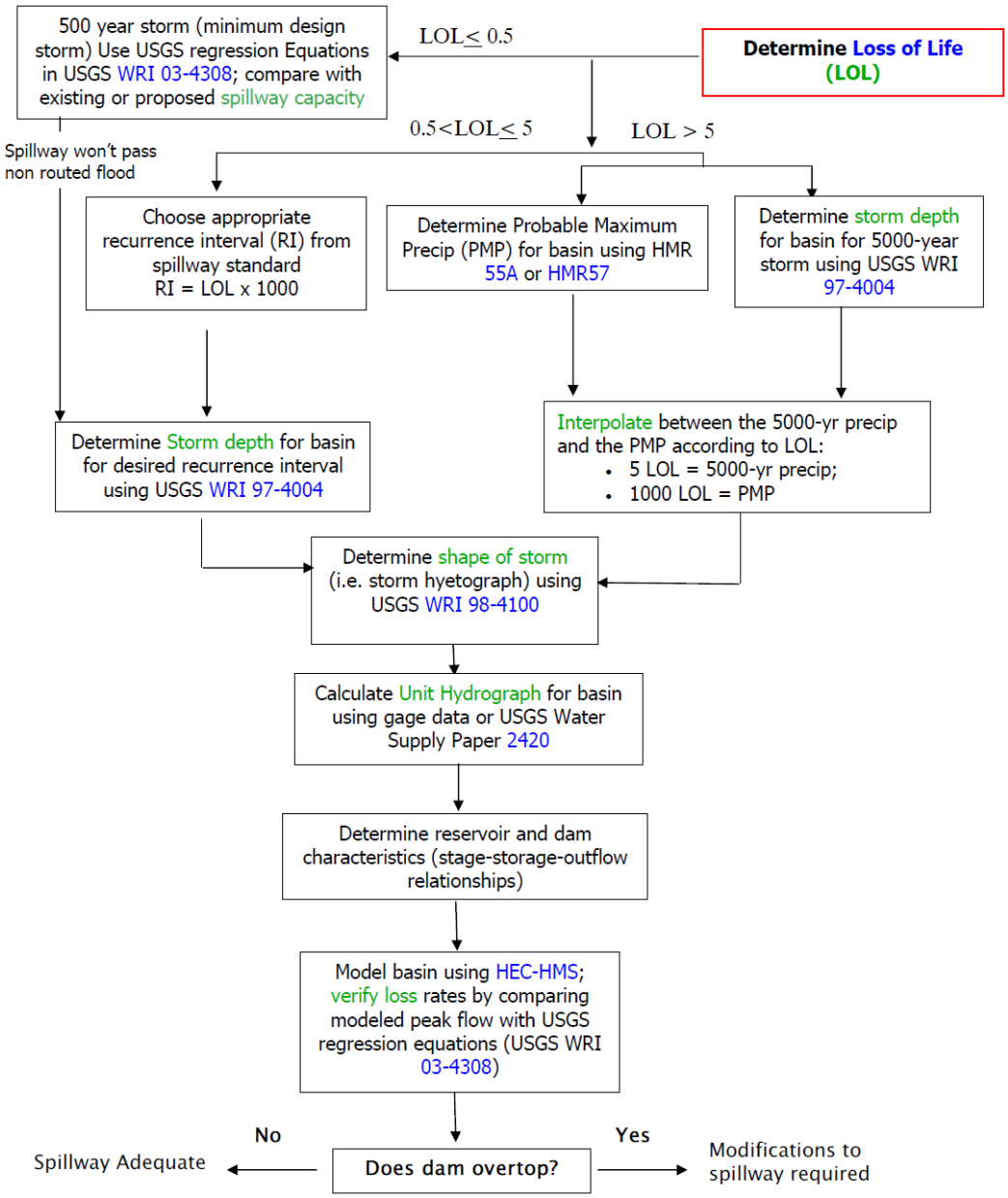


Figure 9.13 Procedure for Determining Spillway Adequacy [Montana DNRC, 2008]

Also inconsistent in the states' approaches are the probabilities of spillway design events required. In California, the minimum SDF is the 1,000-year event while Washington and Montana both allow a minimum of the 500-year event. Even though all three indicate that the PMP/PMF is the maximum event, the different weighting systems, loss of life determination, and other varying criteria could introduce significant deviation in spillway capacity requirements from one state to another.

It may be that risk-based criteria have been structured to meet the perceived needs or societal demands of the issuing agency or state. However, it is also possible that these differences are the result of somewhat subjective choices made by regulatory authorities. In either case, the considerable variety in risk-based criteria will complicate any precise comparisons between criteria used by different agencies. It will also result in a variation or imbalance of risk tolerances with regards to dam safety throughout the country.

9.14. Agency Review

The role of state dam safety agencies in determining the SDF varies from state to state. Only 8 of the 49 state agencies perform an independent verification of all submitted designs. An additional 15 agencies perform both limited detail reviews and in depth verifications as they deem fit (case-by-case basis). Most other agencies perform reviews of the hydrologic design, but do not verify the design independently. A few agencies also act as the designer/engineer for work done on state-owned dams.

10. Receptiveness of States to Changing Guidelines

10.1. The Need for Uniformity

There are many differing opinions regarding the need for uniformity of design criteria between states and federal agencies. It is generally recognized that the implementation of strictly uniform criteria is not a possibility. A flexible framework of criteria would be required to provide for the specific requirements, budget, and technical ability of each state. The NRC Committee's critique of the state-of-the-practice summarizes this issue in the following:

> *"The goal of dam safety is to limit the risks from dam failures to acceptable levels. Probability of failure is controlled partly by design standards and partly by quality of design, construction, inspection, operation, and maintenance. Ideally, hazard failure probability, and acceptable damage would be quantified for the site-specific conditions of each individual existing or proposed dam in order to establish site-specific standards for achieving this goal. With few exceptions, current practices do not involve quantification of these three critical elements for each dam.*
>
> *"Instead, the most widespread current practice is to classify dams in three broad, not well-defined, qualitative damage potential categories (i.e. high, intermediate, and low hazard) and to somewhat arbitrarily assign one of three or four grades or ranges of design standards to each dam depending on its height, storage capacity, and qualitative hazard rating. Current practice treats all of the elements needed for selecting design standards in a generalized way; thus, the appropriateness of the design standards as applied to individual dams is generally unknown.*
>
> *"In defense of this current general practice, it must be recognized that most of the scores of federal and state regulatory agencies each have hundreds to thousands of dams under their jurisdictions. Given their limited resources, as a practical matter, they must use a generalized system of assigning design standards according to generalized hazard and size classifications, at least as an interim step until more detailed site-specific studies can be made. However, the wide range of hazard versus size versus design standards among various agencies reflects a lack of uniformity even within the generalized current practice.*
>
> *"This lack of uniformity in dam classification and safety design standards appears to result from three main factors: (1) lack of interagency and intergovernmental communication, (2) variations in engineering judgment in selecting the generalized standards, and (3) variations in public policy attitudes at the times the standards were selected. In any case, a critique of present practices must point out that, though a generalized approach to selecting design standards is justified as a practical interim step, there is a need for more uniformity among the various federal and state agencies in establishing size and hazard definitions and correlative design standards"* [NRC, 1985].

10.2. Awareness of Existing Federal Guidelines

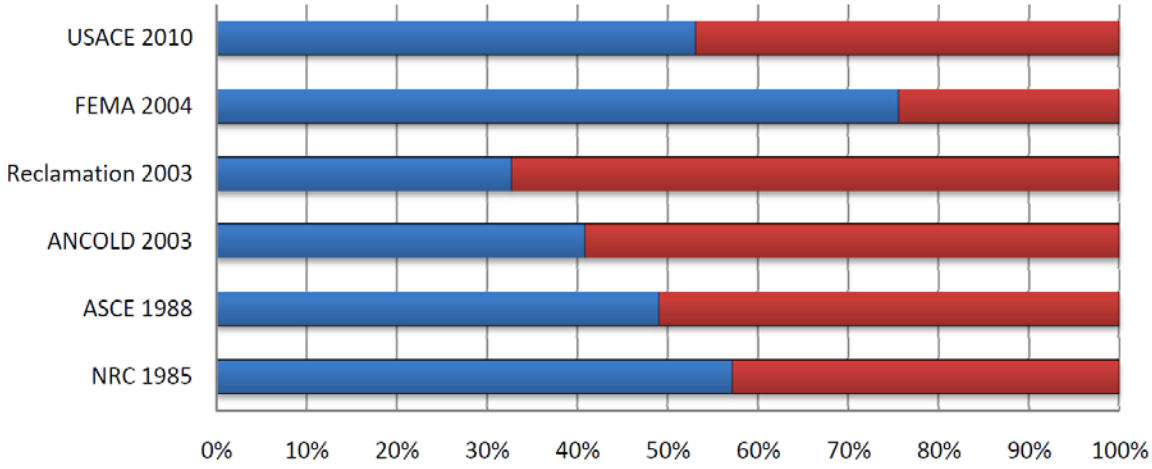
As noted in Section 9.1, the majority of states adopted guidelines or regulations regarding the SDF in the 1970s and 1980s. Since then, each state dam safety agency has had varying degrees of success in updating these guidelines. Some states have recently revised their guidelines or maintain a continuous process of revision and are very aware of current research and recommendations regarding dam safety. Other agencies which are under-staffed or under-funded have limited time to give to such activities. As part of the survey, all agency representatives were asked if they were aware of several documents published on the federal and international levels regarding spillway design criteria. These documents are as follows:

1. Safety of Dams: Policy and Procedures (ER 1110-2-1156), *Draft Version* – U.S. Army Corps of Engineers [USACE, 2010]
2. Federal Guidelines for Dam Safety – Selecting and Accommodating Inflow Design Floods for Dams – Federal Emergency Management Agency [FEMA, 2004]
3. Guidelines for Achieving Public Protection in Dam Safety Decision-making - U.S. Bureau of Reclamation [Reclamation, 2003]
4. Guidelines on Selection of Acceptable Flood Capacity for Dam & Guidelines on Risk Assessment – Australian National Committee on Large Dams [ANCOLD, 2000 & 2003]
5. Evaluation Procedures of Hydrologic Safety of Dams – Prepared by the Task Committee on Spillway Design Flood Selection of the Committee on Surface Water Hydrology of the Hydraulics Division of the American Society of Civil Engineers [ASCE, 1988]
6. Safety of Dams: Flood and Earthquake Criteria – Prepared by the Committee on Safety Criteria for Dams, National Research Council [NRC, 1985]

The results are shown in Figure 10.1 and indicate that a significant portion of the dam safety community is unaware of current and even long-standing publications regarding the hydrologic safety of dams. A quarter of respondents were unaware of FEMA's federal guidelines for inflow design. It is apparent that any attempt to encourage the adoption of more uniform guidelines would require a significant outreach and educational effort on the part of FEMA.

10.3. Perception of PMP and PMF Criteria

When asked if they thought that designing for the PMP/PMF is unreasonably conservative, 31% of the respondents agreed. Fifty-one percent indicated that the PMP/PMF is a reasonable design criterion. The remaining 18% were either neutral or undecided (See Figure 10.2). This is interesting when considering that about half of the states require a full PMP/PMF design for high hazard structures, and in over 80% of the states, the SDF range extends up to the full PMP/PMF. It is also interesting to note that in Dubler's 1995 survey, only 17% of the states agreed that the PMP/PMF was unreasonably conservative, and none of those respondents strongly agreed. Conversely, 76% of states indicated in the 1995 survey that the PMP/PMF was a reasonable design criterion (59% indicated strongly disagreeing that the PMP/PMF was unreasonable).



	NRC 1985	ASCE 1988	ANCOLD 2003	Reclamation 2003	FEMA 2004	USACE 2010
Aware	57%	49%	41%	33%	76%	53%
Unaware	43%	51%	59%	67%	24%	47%

Figure 10.1 Awareness of Previously Published Spillway Design Guidelines

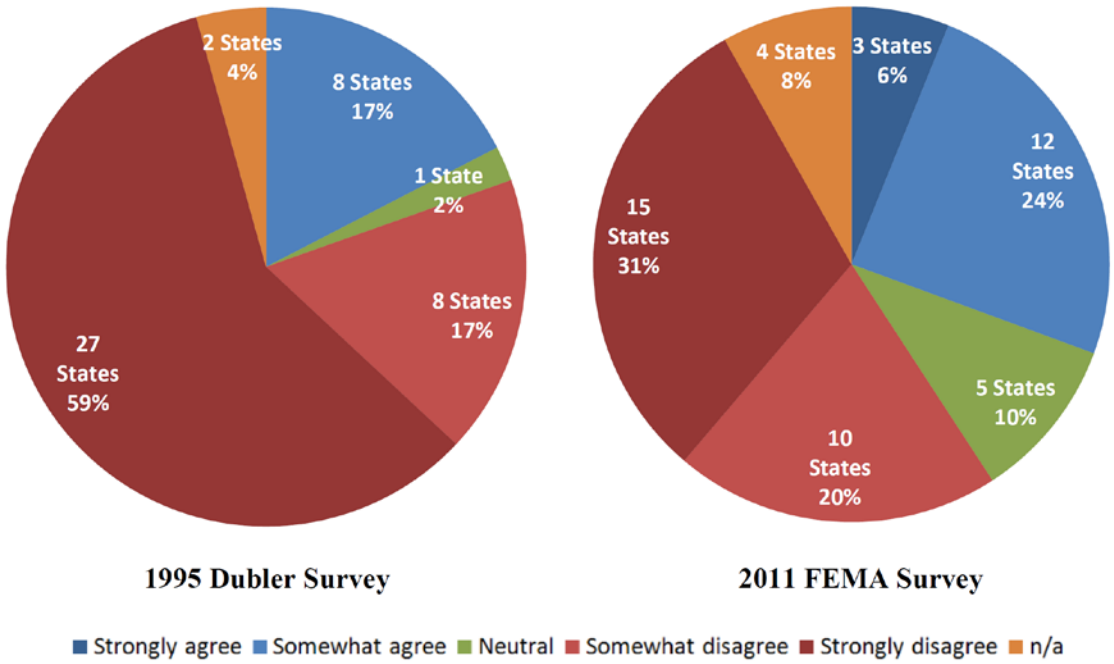


Figure 10.2 Do you agree that designing for the PMF is unreasonably conservative?

While these opinions indicate that a slight majority of the professional community supports design for the PMP/PMF, it also indicates that existing guidelines and spillway design criteria do not align with the current views of all dam safety professionals. Over the past 15 years, support for the PMP/PMF design in general appears to have diminished.

10.4. Concerns Regarding Consistency of Hydrologic Analyses

Many different design methods and models are currently used by dam designers. Twenty-six of the states indicated that they have concerns regarding the consistency of hydrologic and hydraulic analyses. Many of these concerns seem to stem from a general lack of training and experience of consultants as well as varying levels of detail given to the analyses. The variability of inputs into models, the various models used, and the inherent uncertainty in the computational methods and data are common sources of variability in analysis results.

10.5. Perception and Concerns Regarding Risk-Based Criteria

While leading federal agencies and a few states have transitioned from strictly prescriptive to risk-based criteria, it is evident that a large portion of the dam safety community doubts the validity and practicality of risk analysis. Fifty-one percent of respondents indicated that they have concerns regarding either the use of risk analyses or incremental damage analysis to determine spillway capacity requirements. Respondents indicated a number of concerns with these approaches to spillway design including the following:

- The complexity of risk analysis makes it expensive and time consuming to either perform or review.
- There is a general lack of minimum design criteria available. Current methodologies are still under development and are neither mature nor proven.
- Risk-based analyses lack consistency.
- Any argument can be justified using risk analysis if data are selectively analyzed and evaluated.
- There are currently no clear or acceptable guidelines for evaluating incremental damage.
- Many dam safety personnel lack training necessary to perform or review such designs.
- Risk analysis is too subjective and could be problematic over time with new development downstream of a dam.
- Risk analysis does not adequately address the worth of human life. “The potential adverse effects of a dam failure make ‘allowing’ a risk threshold somewhat unsettling both morally and politically.”
- Results of such a design may not be defensible during a lawsuit.

Figure 10.3 illustrates the current opinions of state dam safety officials regarding risk analysis, its usefulness, and constraints. This figure also shows the responses to the same survey questions as

Figure 10.3 Opinions regarding risk analysis: 1995 vs. 2011

collected by Dubler in 1995. While there are significant differences of opinions regarding the complexity of risk analysis as well as the litigious nature of society and its implications for dam design, the overall views of state dam safety officials appear to be very similar to those found in the 1995 survey. The past 15 years have seen little change in opinion regarding risk-based analysis for the hydrologic safety of dams.

10.6. Technical Ability and Availability of Staff to Implement and Enforce Guidelines

The training and resources available to state dam safety agencies oftentimes determines the level of enforcement of dam safety guidelines. This also impacts an agency's ability to implement state-of-the-art practices in their state. Survey respondents were asked if they felt their agency and personnel had the resources (availability and budget) and technical ability to review several more recent advances that relate to the hydrologic safety of dams (See Table 10-1). The majority of agencies felt that they lacked both the technical ability and resources to review rigorous risk analyses. With regard to site specific PMP studies, a majority believed they had the technical ability required but lacked the necessary resources. The majority of states have the necessary resources and training to review incremental damage analyses. There are significant percentages of state regulatory agencies which feel they lack both the training and the resources required to review these state-of-the-art practices.

Table 10-1 Resources and Technical Ability of State Dam Safety Agencies

		Site Specific PMP	Incremental Damage Analysis	Rigorous Risk Analysis
Technical Ability	*Yes*	59%	78%	31%
	No	41%	22%	69%
Availability and Budget	*Yes*	41%	57%	22%
	No	59%	43%	78%

10.7. Overall Receptiveness and Obstacles to Changing Existing Guidelines

Fifty-seven percent of the surveyed states believe that increased uniformity in state dam safety guidelines across the country would be beneficial; thirty-nine percent believed that increased

uniformity would not be beneficial; and four percent did not respond to this question. Many indicated that it would be difficult to implement uniformity of the guidelines without eliminating many necessary regional distinctions that are currently in place. A solution would be to provide a uniform framework of guidelines that also provides for the specific requirements, budget, and technical ability of each state.

In general, dam safety officials were more receptive to adopting new recommended guidelines if they resulted in lower SDF criteria as opposed to higher SDF criteria. When asked how difficult it would be to change current regulations, the majority of states responded that it would be difficult. All others indicated a moderate level of difficulty. For many, such changes are expensive and time consuming, often extending over a period of years. Several respondents indicated that the current partisan political climate would also cause difficulty in changing regulations.

Many state representatives indicated that before the states attempt to standardize their guidelines, the major federal agencies who have traditionally led the effort to develop acceptable dam safety standards need to come to agreement. If these federal players could agree on basic items such as condition assessment, spillway standards, and risk determination, then the states would certainly be more receptive to adopting similar criteria.

11. The Current State of the Practice

11.1. Summary

This document, the "Summary of Existing Guidelines for the Hydrologic Safety of Dams," is the first of two documents commissioned by FEMA related to the Hydrologic Safety of Dams. The purpose of this document is to compile available data and to summarize the state of the practice of evaluating the hydrologic safety of dams. The second document will be in the form of guidelines which will assist dam safety programs in evaluating the adequacy of their current hydrologic guidelines.

At the root of this study is the acknowledgement of the basic need for adequate guidelines for evaluating the hydrologic safety of dams. The inventory of United States dams is large, aging and increasing in hazard as the United States becomes more and more developed. This Summary of Existing Guidelines has traced the evolution and history of design flood practice for dams as well as the application of the methodology in formal dam safety guidelines. The existing hydrologic guidelines of many states and federal agencies were written in the 1970s or 1980s. Since that time, significant technological and analytical advances have been made along with better watershed and rainfall information that have improved the analysis of extreme floods and quantification of incremental dam failure consequences. Review of the published policy and guidelines for each state as well as the responses to the detailed survey completed as part of this study have revealed several important findings that can be used to define the current state of the practice regarding the hydrologic safety of dams.

In general, the guidelines for the hydrologic safety of dams are not consistent and vary widely from state-to-state and between federal agencies in many respects. Although some states and agencies have recently updated their guidelines, many states and agencies have not significantly changed their guidelines since their development. Some of those who have changed their guidelines have incorporated some form of risk-based analyses, but the requirements and methodology differ widely.

Some of the most notable inconsistencies in the existing guidelines relate to classification systems. From the most basic criteria for what defines a regulatory or a jurisdictional dam to whether the dam is classified by size, hazard, or not at all, there is no overwhelming majority of configurations for these classification systems. While size classification is used by many states and hazard classification is used by all states, the number of classifications and the distinctions between the classes vary. There is also no consensus on distinctions between new dams and existing dams.

In determining the magnitude of the SDF, most states follow a prescriptive approach in which the design flood is specified based upon the dam's classification (size, hazard, or both). Both probabilistic and deterministic (based on PMP or PMF estimates) criteria are used for the prescriptive approach by the states and agencies. Many of the criteria in prescriptive approaches

are arbitrary with no apparent scientific rationale [NRC, 1985], and the prescribed SDFs for identical dams in different states would have drastically varying magnitudes.

Historically, a few important federal agencies have led the way in the development of dam safety regulations and design standards, and the trend among these agencies is toward incorporating a risk-based approach rather than the prescriptive approach. In fact, USACE is currently partnering with Reclamation, FERC, and TVA to achieve a common risk management framework and guidelines. Internationally, the trend is also toward integrating risk assessment into dam safety procedures. Recent changes to guidelines in Australia and Canada have addressed risk-based approaches.

The transition to risk-based analyses in some states has also begun. The methodologies developed by California, Washington, and Montana reflect an initial movement to make site-specific, cost-effective, and risk-based designs. They also demonstrate how the complexities of risk analysis can be applied in a simplified, standard-based system. Comparison of these three recently developed, risk-based approaches indicates a lack of consistency regarding the criteria used among the systems, the weights assigned to the criteria, and the resultant risk tolerances.

Although the trend appears to be the incorporation of risk-based approaches into guidelines for the hydrologic safety of dams, there are many obstacles to widespread acceptance by state regulatory agencies. The budgets, staff availability, and technical ability of many state dam safety agencies are very limited. Many respondents indicated that they have concerns regarding risk-based analyses to determine spillway capacity requirements due to review requirements and the lack of widely acceptable and defensible guidelines.

It should also be noted that the federal agencies who have led the way in developing risk analysis procedures and tolerances are owners of a significant number of dams. These agencies have been able to utilize the prioritization and ranking aspects of risk analysis to manage their respective portfolios in addition to using quantitative risk analysis in design. The administrative processes and reviews of regulatory agencies, such as FERC, MSHA, and most of the states, differ significantly from that of dam owners like USACE and Reclamation. The application of quantitative risk analysis for dam design in regulatory agencies may be burdensome or even unnecessary. The state dam regulatory agencies of California, Washington and Montana have recently developed risk-based indices to determine acceptable flood capacity; however, none of the states use quantitative risk assessment.

There are many differing opinions regarding the need for uniformity of design criteria between states and federal agencies. It is generally recognized that the implementation of strictly uniform criteria is not a possibility. Instead, a flexible framework of criteria may be required to provide for the specific requirements, budget, and technical ability of each state. While leading federal agencies and a few states have recently transitioned from strictly prescriptive to risk-based criteria, it is evident that a large portion of the dam safety community has significant reservations concerning the validity and practicality of risk analysis. Having one set of federal dam safety

standards for risk determination may help to promote the use of risk-based analysis by states and potentially encourage increased uniformity of state guidelines.

The survey responses also indicate that a significant portion of the dam safety community is unaware of current and even long-standing landmark publications regarding guidelines for the hydrologic safety of dams. A quarter of respondents were unaware of FEMA's 2004 federal guidelines for "Selecting and Accommodating Inflow Design Floods for Dams," and approximately half were not familiar with the most recently published USACE, Reclamation, and ASCE inflow design and dam safety guidelines. It is therefore apparent that any attempt to encourage the adoption of more uniform guidelines and consideration of adopting risk-based criteria will require a more effective outreach and educational effort.

Although the literature search identified several studies that provided information on state practices related to selecting inflow design floods for dams, none of the studies provided a comprehensive compilation of this data. In addition to providing background information for developing new federal guidelines for the hydrologic safety of dams, this report and the associated database provide a comprehensive compilation of current federal and state guidelines that can be used by individual states to evaluate and compare their current guidelines with those of other agencies. As individual states revise their guidelines, this information will provide them with important information that will help them to make informed decisions that should result in more uniformity.