Dams Safety Committee

NEW SOUTH WALES

DSC3B June 2010

ACCEPTABLE FLOOD CAPACITY FOR DAMS

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1. INTRODUCTION

The *normal requirements* of the NSW Dams Safety Committee (DSC) are set out in its guidance sheets with its principal guidance sheet, *DSC Background, Functions and Operations - DSC1A*, outlining the DSC's general operations and authority.

The DSC gives critical consideration to flood capacity of dams because floods and inadequate spillway capacity continue to be a major cause of dam failure world-wide. Accordingly, this Guidance Sheet is provided for the guidance and direction of dam owners and their consultants in the preparation of proposals that demonstrate to the DSC the provision of acceptable flood capacity for dams. It supersedes DSC11, August 1992, and has been prepared to clarify the DSC's normal requirements for Acceptable Flood Capacity (AFC) for prescribed dams in NSW. It takes into account the latest requirements and developments in the Australian National Committee on Large Dam's (ANCOLD) guidelines on dam safety, including incorporation of the risk assessment process, and associated Engineers Australia's *Australian Rainfall and Runoff* (ARR) revised national guidelines on extreme flood estimation. Reference should also be made to the selected Glossary (and acronyms) appended to this sheet, and to other relevant DSC Guidance Sheets on requirements for reporting and maintaining safety of dams. In particular, the demonstration of acceptable flood capacity is to fit within the overall framework set out in *Demonstration of Safety for Dams - DSC2D.*

This guidance sheet is limited to guidance on the means by which dam owners are to demonstrate to the DSC that the flood risks posed by their dams to community interests are tolerable or will be made tolerable following improvements in safety. However tailings and ash dams may have additional specific requirements on water management, particularly environmental restrictions on liquid and tailings releases. In those cases, reference should be made to the DSC's guidance sheet on *Tailings Dams - DSC3F,* as well as to the requirements of agencies responsible for regulation of aspects such as pollution, and safe working practice (e.g. Department of Environment and Climate Change, Department of Primary Industries).

The DSC Flood Capacity Safety Goals and Key Requirements (Section 2) at the start of the sheet are a summary - the whole sheet is to be read for a proper understanding of DSC considerations on flood capacity for dams.

2. DSC FLOOD CAPACITY SAFETY GOALS & KEY REQUIREMENTS

2.1 DSC Flood Capacity Safety Goals

The primary goal of the DSC, relevant to this sheet, is that risks to community interests from the potential for dam failure are demonstrated to be tolerable, if need be following planned safety improvements, the owner's determination in this regard being satisfactory to the DSC. The DSC requires that dam failure risks to community interests are:

- Identified and assessed;

- Reduced as low as reasonably practicable (ALARP) when necessary and as soon as reasonably practicable, in a way that best serves community interests; and
- Kept under review throughout the life cycle of the dams.

The requirements that risks are to be reduced ALARP and as soon as reasonably practicable are to be judged in the context of what course of action is best for the community out of all feasible courses of action.

There is also provision in this sheet for deterministic *fall-back* acceptable flood capacities as well as the progressive improvement of safety where that best serves the interests of the community.

The following sections of this sheet aim to provide direction and guidance to assist dam owners in achieving these DSC goals.

2.2 DSC Key Requirements

This section summarises the DSC requirements outlined in Section 5 of this sheet.

5.1 General

The DSC requires that all proposals for a dam's Acceptable Flood Capacity (AFC), appropriate to the consequences (based on existing conditions or projected future conditions as appropriate) include, at least, an assessment against deterministic (i.e. standards-based) criteria (refer Tables 5.1 to 5.3).

It is the responsibility of the owner to establish appropriate risk management programs and practices and to assess needed actions to ensure DSC requirements are met.

The DSC recommends that owners ensure the community is adequately informed and consulted on dam safety issues for both proposed dams and the safety improvement of existing dams

5.3 DSC Requirements for Long Term Safety

The DSC's *starting point* [see DSC1B] AFC requirements in Table 5.1 are based on the ANCOLD *Guidelines for Selection of Acceptable Flood Capacity for Dams* (March 2000 - Section 8, Table 8.1, and Appendix 2, Sub-section A2.7), and the flood estimation procedures in ARR99, Book VI.

5.5 Deficiencies Requiring Immediate Risk Reduction

The DSC is to be advised by owners immediately when safety issues are brought to attention during a risk assessment, or through other reviews or reports.

The DSC requires that it be formally notified immediately where the Annual Exceedance Probability (AEP) of the Dam Crest Flood (DCF) is found from a hydrologic review of an existing dam to be greater than:

- 1 in 10,000 for Extreme and High A Flood Consequence Category (FCC) dams.
- 1 in 1,000 for High B, High C and Significant FCC dams.

5.6.2 Integration of Flow Control Systems into AFC Assessments

For gated dams, the DSC requires that a spillway gate reliability analysis be included in the owner's AFC proposal. The owner is to demonstrate to the DSC that a dam with spillway gates, having regard to the reliability of the gate system, meets the DSC public safety risk guidelines and such other risk criteria as have been accepted by the DSC (see the requirements of Figure 3 in *Demonstration of Safety for Dams - DSC2D*). The DSC public safety risk guidelines will be found under Principle D.3 in the guidance sheet on *Background to DSC Risk Policy Context - DSC1B.*

5.6.3 Construction Floods

The DSC requirement is that all risks [likelihood and consequences] in regard to dam failure from flood during construction be considered in preparing construction programs. See the last three paragraphs of sub-section 6.17 of *Demonstration of Safety for Dams - DSC2D* for the DSC's requirements.

3. BACKGROUND

The DSC formulated its initial Information Sheet DSC11, on the selection of an Acceptable Flood Capacity (AFC) for prescribed dams, in August 1992. That sheet was largely based on the ANCOLD *Guidelines on Design Floods for Dams, 1986* (ANCOLD 1986), in conjunction with the Engineers Australia's *Australian Rainfall and Runoff, A Guide to Flood Estimation (ARR)* - Revised Edition, 1987 (ARR87), particularly Chapter 13 for estimation of extreme floods relevant to dams. ANCOLD 1986 provided a recommended design flood range from a 1 in 10,000 Annual Exceedance Probability (AEP) flood to Probable Maximum Flood (PMF) for the upper limit High Incremental Flood Hazard Category (IFHC) dams.

Since the issue of DSC11 in August 1992, ANCOLD has adopted a policy in 1994 to integrate risk methodology into dam safety assessment with its issue of *Guidelines on Risk Assessment, 1994* (RA94), and a subsequent revision in 2003 (RA03). In addition, the 1986 ANCOLD *Guidelines on Design Floods for Dams* have now been superseded by the *Guidelines on Selection of Acceptable Flood Capacity for Dams, March 2000* (AFC Guidelines), which incorporates the risk assessment process to assist in hydrologic dam safety review.

The AFC Guidelines endorse the revised flood estimation procedures in Australian Rainfall and Runoff, 1999 (ARR99), Book VI, *Estimation of Large to Extreme Floods* (Nathan & Weinmann, 1999). Book VI supersedes Chapter 13, ARR87, and provides improved, more consistent, hydrologic procedures for application to dams. Flood estimation is now based on rainstorm analysis, including the estimated (operational) Probable Maximum Precipitation (PMP), with assignment of Annual Exceedance Probabilities (AEP) to storms and floods for application in risk assessment.

The transformation of PMP, using the probability neutral procedures, is now nominated as the estimated PMP Design Flood. The estimated Operational PMP and PMP Design Flood could all be exceeded, although the probability is very low (see Appendix B for

some relevant details of extreme storms in comparison to PMP estimates).

ANCOLD has also issued new *Guidelines on Assessment of the Consequences of Dam Failure* (ANCOLD, May 2000) with expanded, quantified consequence ('hazard') categories, superseding the three subjective hazard categories in ANCOLD 1986. The DSC's companion guidance sheet on the *Consequence Categories for Dams - DSC3A,* takes into consideration the updated ANCOLD Consequence Guidelines. The ANCOLD Consequence Guidelines are currently under review.

4. HYDROLOGIC INPUT

4.1 Value of At-Site Monitoring Data

The hydrologist's task is to estimate the magnitude of the flood that corresponds to an adopted risk level, or in some cases, to estimate the risk corresponding to a given flood magnitude. The flood estimation process involves uncertainty which is attributable to a number of factors that include insufficient representative observation, measurement errors, lack of relevance of the available data to the design objective of interest, model uncertainty, and parameter uncertainty.

When assessing the acceptable flood capacity of dams, a large part of the uncertainty stems from the fact that design flood estimates need to be extrapolated well beyond the range of observed floods. The extreme flood events of most relevance to dam safety are the result of storms that have an equal likelihood of occurrence over large regions. Thus the form of extrapolation required beyond the range of observed floods is best conditioned by reference to hydrometeorological information that is collected over these large regions that are subject to the same meteorological conditions. The Bureau of Meteorology and State agencies have spent many years collecting information of relevance to the extrapolation of flood estimates, and the information required for most practical problems is now available across Australia.

However, while information on how best to condition the required hydrometeorological extrapolation is available, the starting point for any extrapolation can only be determined with any confidence through the analysis of data collected at or near the site of interest. The uncertainty associated with model parameters greatly reduces if there is concurrent rainfall and flood data with which to calibrate the flood model. The larger the floods observed and gauged at the site of interest, the less the degree of extrapolation required, and the less the influence of model uncertainty.

There are a number of ways flood estimates can be derived, and where possible efforts should be made to reconcile any differences between alternative estimates to test the reasonableness of the data and models used. Attention should be focused on reconciling estimates that are derived from data and methods that are as independent from each other as possible. Flood estimates based on rainfall-based procedures and flood frequency analyses are well suited for reconciliation purposes, and these can be undertaken whether the estimates are derived using data collected at the site of interest, or transposed in some manner from the surrounding region.

4.2 Guidance to Good Hydrologic Practice

The best source of guidance to flood estimation practice is contained in the most recent edition of AR&R which covers a range of methods that make use of both at-site and regional information. The guidance mainly focuses on the derivation of flood estimates with annual exceedance probabilities more frequent than, or equal to 1 in 100, but the book on the estimation of extreme floods (Book VI of ARR99) is concerned specifically with the derivation of rarer floods that are of direct relevance to dam safety.

It should be noted that AR&R is not intended to be entirely prescriptive or a strict code of practice. The majority of ARR99 relies on data and methods developed prior to the early 1980s, and over the intervening period some guidance has been superseded because more data has become available and improved procedures have been developed. Details of new design flood estimation procedures appear regularly in refereed journals and conference proceedings, and over time the better methods are adopted and possibly further refined by independent practitioners.

Practitioners are encouraged to consider the adoption of improved procedures, but they should only do so after critical evaluation to ensure that they are appropriate to the particular set of circumstances. Any departure from AR&R guidelines should be described and justified in the documentation used to support the flood estimates provided. AR&R is updated periodically in order to incorporate improved understanding, data and procedures, and it is the responsibility of the practitioner to ensure that the most recent version of AR&R is considered.

It may also be prudent for practitioners to consider the possible effects of Climate Change in their studies as this is already the situation in a variety of other major infrastructure investments around Australia. While it is acknowledged that this area is an evolving science, dam owners should be cognisant of any guidelines already in place, or in preparation, including ARR 2013.

4.3 Value of 'Considered Estimates'

The derivation of flood estimates involves, as does any engineering discipline, the careful consideration of uncertainty. Some sources of uncertainty can be reduced through the further investment of effort and resources, but for the foreseeable future some elements of extreme flood estimation need to be accepted as "unknowable" and such uncertainties cannot be reduced further.

The AR&R guidelines recognise these different types of uncertainties by introducing an increasing level of prescription for estimates that extend beyond the credible limit of extrapolation. That is, the guidelines encourage practitioners to explore a range of different methods and approaches where supported by relevant data, but as the degree of extrapolation increases beyond the observable record, there is a corresponding increase in the requirement for practitioners to adhere to the recommended procedures. While this increasing level of prescription does not reduce the uncertainty involved, it does tend to reduce the variation in flood estimates attributable to differences in methodology and the decisions made by different practitioners.

The guidelines are framed to provide practitioners with estimates that lie in the mid-range of the uncertainty band, which suits the incorporation of flood loadings into a risk analysis framework. The only possible exception to this is the Probable Maximum Flood, which explicitly involves a degree of conservatism in the concept that it represents a limiting value of flood that could be *reasonably* expected to occur. The emphasis provided in AR&R on the importance of reconciling estimates obtained from different methods is one practical means of ensuring that the design floods represent "best" estimates that are not biased towards a conservatively low-risk or high-risk outcome.

Recognition of the impacts of uncertainty should be incorporated into management decisions. If there are significant differences in outcome within the range of uncertainty, then the likely range of outcomes must be explicitly considered in a risk management framework when developing mitigation strategies. Monte-Carlo techniques provide one practical method of characterising the increasing band of uncertainty associated with extrapolation, though such characterisation becomes increasingly notional as the influence of model uncertainty increases.

Regardless of the efforts made, flood estimates relevant to dam safety are generally based on some form of extrapolation and involve a high degree of uncertainty. It is therefore important for decision makers to have an understanding of the nature of these uncertainties and their impacts on decisions. Hydrologists have a key role to play not only in providing the "best possible" design flood estimates, but also in guiding decision makers on the inherent uncertainties involved, as well as how to use this information to make decisions on spillway adequacy.

5. ACCEPTABLE FLOOD CAPACITY

5.1 General

The DSC has adopted the ANCOLD Guidelines (ANCOLD, March 2000 and May 2000) and the revised ARR99 Book VI Guidelines, subject to the qualifications below and in other DSC guidance sheets. Reference should be made to those ANCOLD and ARR guidelines for the specific details, procedures and background that are not repeated in this sheet.

The DSC will assess owners' proposals on dam hydrologic safety, taking into consideration the *normal* requirements of this sheet, along with a case-by-case consideration for each dam, including the particular circumstances, such as the potential consequences of failure and risk to life, and the community input to the owner on the proposals. If an owner seeks DSC acceptance of a flood capacity other than the *normal* requirement of this sheet, a well-reasoned case in support of that flood capacity is to be submitted for the consideration of the DSC. It would usually be expected that the supporting case include a risk assessment (see DSC 2D).

The DSC requires that all proposals for a dam's AFC, appropriate to the consequences (based on existing conditions or projected future conditions as appropriate) include, at least, an assessment against deterministic (i.e. standards-based) criteria (refer Tables 5.1 to 5.3). However, proposals to the DSC should preferably also include a risk

assessment (Sub-section 5.2), with documentation as set out in Sub-section 5.6.

An additional basis for consideration of proposals other than the normal requirements of this Sheet may be Base Safety Condition (BSC - refer Appendix A).

Proposals should take into account the most adverse operating regimes, including any foreseeable long-term changes in reservoir management or behaviour that may affect flood capacity. In particular, for gated dams, the DSC requires that a spillway gate reliability analysis be included in the AFC proposal (see Sub-section 5.6.2).

While the DSC sets requirements to protect the interests of the community, the safety of dams, including their investigation, review, detailed design, construction, operation and safety improvement, along with business risk criteria, is the responsibility of the owner. The owner has the prime responsibility (and consequent liability) to ensure that the community and environment are adequately protected to appropriate safety levels from the possible effects of dam failure. It is the responsibility of the owner to establish appropriate risk management programs and practices and to assess needed actions to ensure DSC requirements are met. Owners also have the responsibility to consider the overall safety level relevant to business asset risk management in addition to the DSC's requirements. This includes responsibilities to consumers and the community, credibility and political issues, and potential financial and legal liabilities arising from the consequences and damages that would result from a dam failure. These business responsibilities may warrant a higher level of safety than that indicated by the DSC's requirements. The DSC would not object to the provision of a higher level of safety unless that would adversely affect the achievement of tolerable risk to community interests, either on the dam in question or elsewhere in the owner's portfolio of dams. In the latter situation, the owner should discuss the situation with the DSC.

The DSC recommends that owners ensure the community is adequately informed and consulted on dam safety issues for both proposed dams and the safety improvement of existing dams. Dam owners should co-ordinate arrangements to inform and consult with the community generally, and specifically with those at risk, on the risks and potential consequences of dam failure, including outcomes of risk assessments, and risk reduction options and proposals. Such consultation would generally be undertaken in conjunction with the State Emergency Service (SES) and to satisfy the compliance requirements of the NSW *Environmental Planning and Assessment Act, 1979*.

Also where the safety of a dam has been in question and an owner, having undertaken a safety review, concludes that the dam does not require safety improvement works, the DSC recommends that the community, and relevant stakeholders, be informed and consulted if the decision is a matter of public interest or there are significant societal concerns. There is no need for such consultation, where a dam clearly meets authoritative good practice.

5.2 Integration of Risk Assessment into AFC determinations

Reference should be made to the following Guidance Sheets for requirements on applying risk assessment in the determination of AFC:

- *Demonstration of Safety for Dams - DSC2D* sets out the requirements for *failure modes analysis* (FMA) and the process requirements for estimating and evaluating dam safety risks.
- *Background to DSC Risk Policy Context - DSC1B* sets out the DSC public safety risk guidelines.

5.3 DSC Objectives for Long Term Safety

The DSC's *starting point* (see DSC1B) AFC requirements in Table 5.1 are based on the ANCOLD *Guidelines for Selection of Acceptable Flood Capacity for Dams* (March 2000 – called *fallback* AFC in Section 8, Table 8.1, and Appendix 2, Sub-section A2.7), and the flood estimation procedures in ARR99, Book VI. While Book VI recommends use of the PMP Design Flood instead of PMF, the PMF standard has been retained for the Extreme FCC case in recognition of the potential catastrophic consequences of dam failure; and to provide consistency with common practice in countries of comparable societal conditions and values.

Table 5.1 has been modified from Table 8.1 of the ANCOLD guidelines to give a specific flood for each FCC, rather than ranges of floods with the DSC adopting the conservative [safer] end of the ANCOLD *fall-back* flood capacity range in Table 8.1 of the flood guidelines (ANCOLD 2000a) as *acceptable flood capacity*. Among other considerations, this approach takes account of the variable and uncertain relationship between PAR and loss of life, according to the location of the PAR and other factors. Capacities lower in the range will be considered by DSC provided the owner demonstrates correct transitioning as envisaged by ANCOLD and conditional on the *consequence category* being based on the total *population at risk [PAR]* – prior to any organized or self-evacuation – within the area of the dam-break inundation footprint [including the area affected by natural flooding if the dam did not fail]. If the dam satisfies the DSC *fall-back* flood capacity using total PAR the DSC will accept it as having adequate flood capacity in the long-term – in *risk assessment* inadequate flood capacity would then be regarded as a non-credible failure mode;

Where the check of the *starting point* AFC from Table 5.1 against the DSC *public safety risk guidelines* (see DSC1B) indicates a lower risk AFC [higher flood capacity] than in Table 5.1, the DSC may require that the higher safety level be provided. Alternatively, if a detailed risk assessment outcome indicates a higher risk AFC (lower flood capacity), than that listed in Table 5.1, could be acceptable, then that outcome could be submitted to the DSC for consideration.

If a Base Safety Condition (BSC) study (Appendix A), indicates a flood capacity less than that indicated in Table 5.1 could be acceptable, the BSC can be proposed to the DSC for consideration. Owners need to carefully consider the potential legal difficulties, in the aftermath of a dam failure, in defending the estimated incremental consequences that were used to justify the BSC.

TABLE 5.1 - STARTING POINT AFC

FCC RATING (i)	FLOOD OR AEP (ii)
Extreme	PMF (reservoir full)
High A	PMPDF (reservoir full)
High B	Max of AEP of PMPDF, or 10^{-6} (iii) not necessary to use PMP Design Flood, as PMPDF was used in the previous row for HIGH A)
High C	Max of AEP of PMPDF, or 10^{-5}) (iii)
Significant	10^{-4}
Low	10^{-2} to 10^{-3}
Very Low	No requirements (iv)

Notes

i. The FCC shown in Table 5.1 shall be based on DSC3A. Both the total and incremental Population at Risk are to be reported to the DSC.

ii. All floods, listed in Table 5.1, are outflow floods with estimates of the PMF and the PMP Design Flood to be made in accordance with guidelines provided in ARR99, Book VI. If the outflow flood is sensitive to pre-flood reservoir levels, it may be desirable to undertake a joint probability analysis of inflows and initial reservoir content, as the basis for maintaining AEP neutrality. The adequacy of a dam's flood capacity may be determined by the operating rules for the reservoir and spillway controls. Any proposal to change such rules would require reassessment of acceptable flood capacity.

iii. The AFC for FCC of High B and High C have alternative upper limits, with the more frequent flood to apply (i.e. the smaller of the alternative flood peak discharges). This is to take into account that the assigned AEP relative to catchment area for the PMP Design Flood (EA99, Book VI) could otherwise imply an apparently higher relative safety standard for small catchments (usually with smaller dams, with potentially lesser failure consequences) compared with large catchments. For proposals in these consequence categories, where loss of life would be expected in the event of dam failure, community consultation is recommended in accordance with Sub-section 5.1.

iv. The DSC has no requirements for 'Very Low' Flood Consequence Category (FCC) dams, but considers an AFC of at least 1 in 100 AEP will normally be in the owner's interests in terms of asset protection.

5.4 DSC Objectives for Short / Medium Term Safety and Progress Improvement

The DSC's objective in introducing the concept of progressive improvement is better outcomes in risk reduction for the community from the available resources by:

- Eliminating *intolerable risks* from all dams *as soon as reasonably practicable*; and
- Achieving the *long-term* DSC safety requirements, over all deficiencies and dams, *as soon as reasonably practicable*, having regard to relevant circumstances, in particular the existing level of risk.

A typical framework for *progressive improvement* is set out in Table 2 of The DSC guidance sheet on *Background to DSC Risk Policy Context - DSC1B.*

5.5 Deficiencies Requiring Immediate Risk Reduction

The DSC will judge the urgency of risk reduction by the extent to which the existing risk is higher [more urgent] or lower (less urgent) than the *limit of tolerability* given in the DSC *public safety risk guidelines* (see DSC1B).

RA03 includes a framework for staged reviews during the risk assessment process, including flagging orders of inadequacy, particularly against risk to life criteria. The process will alert the owner on any critical issues requiring immediate action and/or interim measures, such as flood warning systems and possible lowering of the reservoir level, while planning for medium and long term remedial measures proceeds. The DSC is to be advised immediately when such safety issues and inadequacies are brought to attention during a risk assessment, or through other reviews or reports.

A preliminary indication of potential spillway inadequacy can be assessed by comparing the AEP of the *dam crest flood* (DCF) with the AEP of the flood specified for the relevant Consequence Category (see Table 5.1). The DSC requires that it be formally notified immediately where the AEP of the DCF is found from a hydrologic review of an existing dam to be greater (i.e. more frequent) than:

- 1 in 10,000 for Extreme and High A FCC dams.
- 1 in 1,000 for High B, High C and Significant FCC dams.

For embankment dams, such cases would generally require immediate interim action, and a program for detailed investigation for risk reduction measures. For concrete dams, appropriate measures for the specific case should be discussed with the DSC to consider whether safety measures and/or planning are required at that stage.

Where the AEP of the DCF is of less frequent occurrence than specified in this section, the information should be included in the 5 yearly Surveillance Report for consideration with any other matters raised in the report.

5.6 Other Flood Related Issues

5.6.1 Consequence Categories and Incremental Effects

The requirements of the AFC Guidelines are related to the potential consequences of dam failure as quantified in the dam consequence category. The relevant FCC shall be based on the ANCOLD *Guidelines on Assessment of the Consequences of Dam Failure - 2003* (with any DSC3A qualifications).

Owner's should be aware that, whilst the concept of incremental consequences is clearly rational and well established in dam safety practice, it may be very difficult, both technically and legally, in the aftermath of a dam failure to demonstrate the distinction between the incremental and the total consequences. Accordingly, the DSC considers it prudent in a risk assessment study to also consider the impact of the total consequences on the risk outcomes.

5.6.2 Integration of Flow Control Systems into AFC Assessments

For gated dams, the DSC requires that a spillway gate reliability analysis be included in the owner's AFC proposal. The reliability analysis is to consider the failure probability of individual components, as well as common cause failure events (e.g. power loss) to assess the dam's probable flood capacity (see DSC3D for more background information in this area).

The owner is to demonstrate to the DSC that a dam with spillway gates, having regard to the reliability of the gate system, meets the DSC public safety risk guidelines and such other risk criteria as have been accepted by the DSC (see the requirements of Figure 3 in *Demonstration of Safety for Dams - DSC2D*). The DSC public safety risk guidelines will be found under Principle D.3 in the guidance sheet on *Background to DSC Risk Policy Context - DSC1B*.

5.6.3 Construction Floods

During construction (or modification) of a dam, the dam is exposed to a higher risk profile and dam owners (and their construction phase planners) are referred to some examples of unforeseen risks that can arise in this area in the DSC note on "Risks during Construction" (see references). Accordingly, the provisions for passage of floods during construction [new dams or modifications of existing dams] should be based on risk assessment that considers the potential economic loss from a flood failure, as well as risks to the safety of workers and any community at risk.

For construction of new dams, the risks typically change as construction proceeds, with the probability of failure declining but the consequences of failure increasing as the level of the dam rises. Risk assessment needs to examine the risk profile over the full project duration.

The arrangements would normally include flood warning and evacuation plans developed with the SES and community at risk but overall dam owners (and their construction contractors) are responsible for community safety during dam construction.

Each case will be site specific, with consideration of phasing critical construction during seasonal low flow periods to minimize risks. The likelihood that construction would inadvertently extend into the higher flood risk seasons must be considered and specific revision of the arrangements listed above need to be set out if a higher flood risk season is to be entered.

There have only been limited references in formal international guidelines on selection of construction floods (ANCOLD Mar 2000, ICE 1996 and CDA 1999) and no formal guidelines for application of risk to life criteria. It is noted that there could be practical difficulties in meeting normal risk to life criteria, but the ALARP process, with a consideration of what is practicable, may provide a basis for decision.

The DSC requirement is that all risks [likelihood and consequences] in regard to dam failure from flood during construction be considered in preparing construction programs. See the last three paragraphs of sub-section 6.17 of *Demonstration of Safety for Dams - DSC2D* for the DSC's requirements.

5.6.4 Freeboard

Freeboard for wind and other effects should generally be provided, as may be appropriate for the specific case, depending on the likely duration of flooding with wave splash and/or overtopping, and the dam's resistance to overtopping (refer AFC Guidelines Sub-section 4.5 and Appendix 2, Sub-section 2.5).

For proposed dams, it is prudent to consider conservative freeboard provisions in view of:

- the potential settlement of the crest of embankment dams;
- possible increases in estimated flood discharge due to developments in meteorology and estimates of extreme rainfalls;
- possible increases in estimated flood discharge due to developments in hydrologic methodology;
- the generally low incremental cost of providing additional flood capacity.

It should be noted that freeboard can be a significant component of overall dam safety and considerations on the need for freeboard provisions are more critical for embankment dams, as these dams are generally more susceptible to breaching and failure on overtopping.

Concrete dams can sometimes tolerate the increased loading associated with some overtopping, and as such may not require positive freeboard. In some cases concrete dams can accept a negative freeboard, that is some overtopping of the non-overflow crest at the larger floods. As noted in the AFC Guidelines, there are other specific flood safety considerations for concrete dams, such as increased loading from the flood stage reservoir level, or the potential for scour of the toe of the dam or the abutments, which could affect stability.

Provisions proposed for freeboard and the associated dam safety flood capacity and relevant AEP shall be indicated in submissions on AFC (refer Sub-section 5.1). Minimum freeboard for proposed embankment dams should be considered as indicated in Table 5.2.

Table 5.2 - Proposed Embankment Dam Freeboard

FCC	Minimum Freeboard (m)
Extreme and High A	0.6
High B and High C	0.4
Significant	0.3

For existing embankment dams, the freeboard provision can alternatively be considered as an integral part of the safety risk assessment. Consideration may be given to no freeboard, or a freeboard less than that of Table 5.2, on submission of a well-supported risk analysis and having regard to:

- consideration of correlation between adverse winds and peak level in the reservoir due to the flood;
- the joint probability of wind velocity and reservoir stage; and
- the duration of overtopping and resistance to overtopping.

For all dams the specific consideration of provision, or not, of freeboard shall be indicated in proposals to the DSC.

5.6.5 Dam Safety Emergency Plans (DSEP) and Flood Plans

The DSC's general requirements for DSEPs and Flood Emergency Plans (FEP) are set out in the DSC's guidance sheet on *Emergency Management for Dams - DSC2G.*

Generally such emergency plans, with their flood warning and evacuation procedures, will not be accepted by the DSC as an alternative to providing the AFC for proposed dams, whether proposed or existing.

However, the DSC recognises that emergency plans, including dam break warning and evacuation procedures, can substantially reduce the risks to the public in the event of a dam failure. Accordingly, the DSC requires such plans wherever public safety is at risk. In preparing the plans, dam owners are to consult with the SES, which is legally responsible for flood planning in NSW.

The DSC also considers it essential that the dam owner demonstrates community consultation and acceptance of the emergency planning, and provides a regular review process to ensure the community continue to be informed, and that the planning continues to be practical and appropriate. It may be necessary for the owner to allocate resources, both short and long term, to ensure the warning process is appropriate.

5.6.6 Concurrent Floods

In some situations it is desirable to estimate the flooding that occurs on an adjacent catchment, usually downstream, concurrently with the design flood. An example of such a situation would be when the magnitude of flows from a tributary has the potential to impact on the consequences of a dam failure. Although various methods have been adopted previously, when determining the appropriate magnitude or AEP of concurrent flooding to adopt, the guidelines in the most recent edition of Australian Rainfall and Runoff (AR&R) should be adopted.

The recommended AR&R approach is the undertaking of a joint - probability analysis of the occurrence of floods in the catchment of interest and tributaries or adjacent catchments in order to ensure AEP-neutrality. However, AR&R recognises that undertaking of a joint probability analysis may be outside the scope of normal flood studies and therefore presents an approximate procedure based on determining the correlation between large flood historic events at the two sites. In the absence of historic flood information a procedure based on correlations based on rainfall data is also provided.

5.7 Documentation of AFC Proposals

Detailed information, additional to that required by other DSC guidance sheets and forms, shall be submitted to the DSC with hydrologic review of existing dams, and with AFC proposals for new dams or risk reduction of existing dams. The information for different circumstances is summarized in Table 5.3 and the flow charts for assessment are given in *Demonstration of Safety for Dams - DSC2D*. The DSC can then consider all factors in relation to overall assessment of dam hydrologic safety and appropriate safety levels for risk reduction.

Table 5.3 - Information Required by the DSC

Review of Existing Dams Following completion of a hydrological review for the dam (peer reviewed where required in accordance with DSC3G)	• Dam Crest Flood (DCF), PMF & PMPDF with the assigned Annual Exceedance Probability (AEP), to ANCOLD *Guidelines on Selection of Acceptable Flood Capacity for Dams,* Appendix 1. • Flood frequency curves for the dam. • For dams with FCC of Extreme, PMF, based on Book VI, ARR (Nathan & Weinmann, 1999) procedures, with FSL the pre-flood reservoir condition, and including information on the assigned values for all influencing parameters such as temporal and spatial patterns and losses. • For dams with FCC of High A, High B or High C, PMP Design flood based on Book VI procedures as above. For High A dams, the pre-flood reservoir condition is to be FSL. If, for High B or High C dams, a joint probability analysis is also carried out to take account of initial reservoir content, then the information shall include the reasons for the assigned parameter values, the methodology used and the historical and/or simulated reservoir level data that are available. • The assessed FCC, and potential consequences, noting any changes to potential consequences since the previous review report-both total and incremental consequences are to be reported including the potential for loss of life. • For gated dams, a spillway gate reliability analysis and/or other integration of flow control systems analyses (and does this requirement need referencing in the RA Guidance Sheet?) • Note of any changes to dam management, operating rules, conditions and surveillance procedures since the previous review report. • Information on DSEPs and FEPs in place. • Identified hydrologic deficiencies including assessment against deterministic criteria. • Basis of the risk assessment process, if used, methodology, parameter values and uncertainties, estimated risks and their tolerability. • Completed DSC D6 form summarizing flood studies (see form at p22).
Risk Reduction Proposals for Existing Dams	• Assessed FCC and potential consequences for the existing dam-both total and incremental consequences are to be reported including the potential for loss of life. • Existing DCF, PMF and/or PMP Design Flood, with assigned AEP, as above and appropriate. • Flood frequency curves for the dam. • For gated dams, a spillway gate reliability analysis and/or other integration of flow control systems analyses. • Note of any changes to dam management, operating rules, conditions and surveillance procedures since previous review.

Following the completion of an assessment for the dam (peer reviewed where required in accordance with DSC3G)	• Information on DSEPs and FEPs in place.
	• Identified hydrologic deficiencies including assessment against deterministic criteria.
	• Basis of the risk assessment process, if used, methodology, parameter values and uncertainties, estimated risks and their tolerability.
	• Risk reduction options considered and comparative assessments.
	• Outcomes of public consultation on risk reduction proposals, including owner's consideration of comments.
	• Proposed risk reduction measures information including:
	  • Upgrading proposal(s), if planned;
	  • Proposed post-improvement DCF, PMF and/or PMP Design Flood, with assigned AEP, as appropriate;
	  • Assessed FCC, and potential dam failure consequences, after risk reduction and for the long term;
	  • Proposed changes to dam management, operating rules, conditions and surveillance procedures;
	  • Proposed short and long term DSEP, with details of any Flood Warning System proposed for risk reduction.
	• Where upgrading works are planned:
	  • Proposed freeboard provisions and reasons;
	  • Proposals, including assessed risks, for flood management during construction;
	  • Interim DSEPs, both during planning and, during construction;
	• Completed DSC D6 form summarizing flood studies (see form at p22).

Proposed Dams Following EIS, to be submitted with D2 Form. (Hydrological report to include peer review where required in accordance with DSC3G)	• Assessed FCC and consequences-both total and incremental consequences are to be reported including the potential for loss of life. • Hydrologic assessment against deterministic criteria. • DCF and PMF and/or PMP Design flood, as for review of existing dams, as appropriate. • Flood frequency curves for the dam. • Proposals for freeboard provisions and reasons. • Proposals, including assessed risks, for flood management during construction. • Outcomes of public consultation and comment, and the owner's consideration of comments received. • DSEPs, both construction and long term. • For gated dams, a spillway gate reliability analysis and/or other integration of flow control systems analyses. • Proposed dam management operating rules, conditions and surveillance procedures. • Completed DSC D6 form summarizing flood studies (see form at p22).

6. REFERENCES

- ANCOLD(Australian National Committee on Large Dams), 1986, *Guidelines on Design Floods for Dams*.
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APPENDIX A

BASE SAFETY CONDITION (BSC)

For hydrologic loading, the BSC is considered as the flood capacity of a dam beyond which the incremental consequences of dam failure are assessed as acceptable for the specific case. A BSC study requires assessments of incremental effects over a range of floods, and a risk assessment should include this possibility.

Particularly for larger dams, it is likely that incremental effects will still be significant for the extreme flood case. However the BSC may be relevant for upgrading of some existing dams to an appropriate hydrologic safety. In such cases the DSC would be prepared to consider proposals for the BSC as an acceptable AFC.

For proposed dams, which impose a new and long term hazard on the community, higher standards than the BSC (or risk assessment options) may be prudent, having regard to the difficulties in foreseeing community and consequence changes, and subsequent increased risks, and changes in the extreme flood estimates during the long life of the dam, say to 100 years ahead. It is also likely that there will be a relatively small incremental cost of providing larger flood capacity for a proposed dam.

An owner considering a proposal that relies on BSC should be aware that, whilst the concept of incremental consequences is clearly rational and well established in dam safety practice, it may be very difficult in the aftermath of a dam failure to demonstrate the distinction between the incremental and the total consequences. See also sub-section 6.10 of *Demonstration of Safety for Dams - DSC2D.*

APPENDIX B

EXTREME POINT RAINFALL DATA

Generalised Tropical Storm Model (GTSM) storms that give the maximum percentage of PMP for a specified area and duration

Duration (hrs)	Area (km²) 100	1000	5000	10000	60000
24	71 1916DEC29-2	68 1916DEC29-2	71 1916DEC29-2	68 1916DEC29-2	61 1976FEB09-2
48	65 1979JAN06-4	61 1911APR03-5	57 1974FEB01-5	58 1974FEB01-5	59 1976FEB09-2
72	69 1979JAN06-4	65 1911APR03-5	59 1911APR03-5	57 1911JAN09-5	53 1918JAN25-5
96	73 1979JAN06-5	64 1911APR03-5	59 1893FEB06-7	57 1893FEB06-7	54 1974FEB01-5
120	76 1979JAN06-5	64 1911APR03-5	59 1893FEB06-7	58 1893FEB06-7	59 1974FEB01-5

Generalised South-east Australia Model (GSAM) storms that give the maximum percentage of PMP for a specified area

Area (km^2)	100	500	1000	2500	5000	10000	20000
Coastal Zone(%)	70	72	80	80	70	70	68
Inland Zone(%)	60	60	60	60	62	75	85

GLOSSARY

SELECTED TERMINOLOGY

(Refer DSC1A and ANCOLD Guidelines for full Glossaries)

TERM	DEFINITION
Acceptable Flood Capacity (AFC)	The AFC for a specific dam is the flood capacity, including freeboard as relevant, which provides an appropriate level of safety against a flood initiated dam failure to protect the community and environment to tolerable risk levels, within the total context of overall dam safety from all causes.
ALARP	As Low as Reasonably Practicable Principle. This states that risks, lower than the Limit of tolerability, are tolerable only if the risk reduction is impracticable or if its cost is grossly disproportionate (depending on the level of risk) to the improvement gained [HSE, UK]
Annual Exceedance Probability (AEP)	Probability at which an event of specified magnitude will be equalled or exceeded in any year.
Base Safety Condition (BSC)	The flood capacity of a dam beyond which the incremental adverse consequences of dam failure are assessed as acceptable.
Crest of dam	The uppermost surface of the non-overflow section of the dam proper, excluding parapets, handrails etc unless capable of supporting the flood surcharge load.
Dam Crest Flood (DCF)	The flood event which, when routed through the reservoir, results in a still water level in the reservoir, excluding wave effects, which: • For an embankment is at the lowest point of the embankment crest, unless a parapet is capable of supporting the flood surcharge load • For a concrete dam is at the uppermost level of the crest, excluding handrails and normally parapets, unless the parapet is capable of supporting the flood surcharge load. • For a concrete faced rockfill dam, is the lowest point of the crest, unless a parapet is capable of supporting the flood surcharge load.
Dam Safety Emergency Plan (DSEP)	A continually updated set of instructions and maps that deal with possible emergency situations or unusual occurrences at a related dam.
Flood Consequence Category (FCC)	The potential losses and damages (usually incremental) directly attributable to the failure of a dam due to a flood condition.
Freeboard	The vertical distance between a stated water level and the top of the non-overflow section of a dam. The part of the freeboard that relates to the flood surcharge is sometimes referred to as the “wet freeboard”, and that above the flood surcharge, due to wind and other effects, is sometimes referred to as the “dry freeboard”.

TERM	DEFINITION
PMP Design Flood	The PMP Design Flood is the flood derived from the PMP using AEP-neutral assumptions, and as such it is estimated to have the same AEP as the PMP.
Probable Maximum Flood (PMF)	The flood resulting from PMP, and where applicable snow melt, coupled with the worst flood-producing catchment conditions that can be reasonably expected. As AEP neutral assumptions are specifically rejected, an AEP cannot be assigned to the PMF.
Probable Maximum Precipitation (PMP)	The theoretical greatest depth of precipitation for a given duration that is physically possible over a particular catchment area, based on generalised methods. The PMP estimated using Bureau of Meteorology methods is referred to as the operational estimate of PMP.
Retarding (Detention) Basin	A dam primarily designed to mitigate flooding in downstream populated areas.
Risk	Measure of the probability and severity of an adverse effect to life, health, property, or the environment. Risk is estimated by the mathematical expectation of the consequences of an adverse event occurring (i.e. the product of the probability of occurrence and the consequence) or, alternatively, by the triplet of scenario, probability of occurrence and the consequence.
Risk Analysis	"Risk Analysis" is the use of available information to estimate the risk to individuals or populations, property or the environment, from hazards. Risk analyses generally contain the following steps; scope, definition, hazard identification, and risk estimation.
Risk assessment	*"Risk assessment"* is the process of deciding whether existing risks are tolerable and present risk control measures are adequate and if not, whether alternative risk control measures are required. Risk assessment incorporates, as inputs, the outputs from the risk analysis and risk evaluation phases.
Risk-based decision making	Decision-making which has as a main input the results of risk assessment. It involves a balancing of social benefits and residual risks
Risk evaluation	*"Risk evaluation"* is the process of examining and judging the significance of risk. The risk evaluation stage is the point at which values (societal, regulatory, legal and owners) and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.
Service Reservoir	Reservoirs designed to store water in populated areas for daily distribution of water to that population.

New South Wales Government

NSW Dams Safety Committee

D6 Form

Flood Security Status Form

(to be included in Flood/Hydrology Studies)

1. Dam Name: .....
2. Owner of dam: .....
3. Catchment Area: ..... km^2
4. Flood Consequence Category (Refer to DSC3A): .....
5. Required Acceptable Flood Capacity (Refer to DSC3B – Table 5.1): .....

   .....
6. Method of rainfall derivation: .....
7. Method of inflow hydrograph derivation: .....
8. Peak PMF Inflow: ..... m^3/s
9. Peak Design Inflow Flood: ..... m^3/s
10. Peak Design Outflow Flood: ..... m^3/s
11. Spillway Capacity (or Dam Crest Outflow Flood): ..... m^3/s
12. Estimate of AEP of the Spillway Capacity (or Dam Crest Flood): .....
13. Hydrologist's assessment of Flood Capacity provided? (compare 10 & 11 above)

    .....

.....

Signature of person completing this form

.....

Name and organisation of person completing this form

.....

Date of completion of this form

This Guidance Sheet is one of a series available from our Website at:

http://www.damsafety.nsw.gov.au

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ISSN 1039-821X