

Guidelines on Acceptable Flood Capacity for Dams

February 2007

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1 Purpose, scope and structure of the guidelines

Dams play a vital role in our lives. They meet demand for drinking, irrigation and industrial water supply; they control floods, increase dry-weather flows in rivers and creeks and give opportunities for various recreational activities. But besides being a valuable resource, dams can also be a source of risk to downstream communities with dam failure potentially resulting in unacceptable damage to property and loss of life. One of the main causes of dam failure is the overtopping of dams because of inadequate flood carrying capacity.

S.491 (4A) of the *Water Act 2000* empowers the chief executive of the Department of Natural Resources and Water (NRW) to issue guidelines for applying safety conditions to referable dams. This document is a guideline issued by a duly authorised delegate of the chief executive pursuant to s.491 (4A). Dam safety conditions in relation to flood adequacy will be applied to referable dams in accordance with these guidelines.

The aim of these guidelines is to present the Queensland Government's flood adequacy policy against which all referable dams in Queensland will be assessed and to alert the dam owners to their wider responsibilities and liabilities in ensuring the safety of their dams.

The general principle is that a dam whose failure would cause excessive damage or the loss of many lives should be designed to a proportionally higher standard than a dam whose failure would result in less damage or fewer lives lost.

These guidelines relate to the flood safety of water dams, and more specifically, to the selection of an Acceptable Flood Capacity (AFC) and adequate spillway provisions for all proposed and existing referable dams in Queensland¹.

These guidelines detail the:

- available methods for determining the required flood discharge capacity for referable dams
- procedures to be followed when applying these methods
- reporting requirements when reporting the results of these investigations to the chief executive of NRW
- timeframe for any necessary dam safety upgrades.

These guidelines present three methods for assessing AFC for referable dams:

- Small dams standard
- Fall-back option
- Risk assessment procedure (incorporating ALARP).

The *Small dams* standard is a method, which allows the owners of small earth dams to quickly assess spillway adequacy. It is essentially a simplified "Fall-back" method, which relates the Acceptable Flood Capacity directly to the population at risk.

The *Fall-back* option is intended for larger dams where the cost of undertaking a full risk assessment is not warranted when weighed against the potential benefits.

¹ Under the *Water Act 2000*, referable dams are those assessed using NRW's *Guidelines for Failure Impact Assessment of Water Dams (NRM, 2002b)* as having a population at risk of 2 or more in the event of any potential failure of the dam.

In terms of safety, the traditional engineering approach has always been to specify the required flood discharge capacity for the dam at the design stage based on the relevant hydrological data and flood estimating and flood routing procedures. Hydrologic safety was considered separately from other risks, which resulted in identification of inadequate spillway capacity as a major cause of dam failure.

More recent risk based approaches, such as that put forward by ANCOLD (ANCOLD 2003), indicate that hydrological safety should be assessed within the total load context in order to identify the priority of dam safety inadequacies and dam failure scenarios. Dam failure scenarios may include (but are not limited to) piping at dam headwaters elevated by flood, spillway malfunction or severe scour at lesser floods than extreme.

The risk assessment procedure is based on the ANCOLD risk assessment process and is consistent with the framework of the national standard AS/NZS 4360:2004 Risk Management. It is a comprehensive tool intended to enable the dam owner to evaluate the deficiencies and available risk reduction options. This type of assessment should be adopted for major dams. The risk assessment procedure provides the owner with a review of the adequacy of the dam under all load conditions and failure scenarios, not just flood loadings. It also has the capability to more realistically assess the Acceptable Flood Capacity of gated spillway operations and the likelihood of premature failure due to causes such as spillway erosion.

Dam owners should note that, while these Guidelines set minimum requirements to protect the interests of the community, it is the responsibility of the owner to ensure the safety of dams, including their investigations, design, construction, operation, safety review and remediation.

Dam owners should realize that many of the rainfall estimates from years past are well below current estimates. In many cases the design floods may change over time as the techniques for determining extreme rainfalls are progressively refined and more detailed flood studies are undertaken for each dam.

It is the dam owners prerogative to adopt a higher safety standard where the owner considers that this is necessary from a business risk perspective.

Dam owners should also note that these guidelines set out the normal requirements of the chief executive of NRW. Where dam owners believe that a departure from these normal requirements is warranted, they should submit proposals for the chief executive's consideration with reasons in support of the proposed departure.

2 Requirements of the *Water Act 2000*

The *Water Act 2000* (the Act) provides the regulatory framework for dam safety of water dams in Queensland. Under s.491 of the Act the chief executive has the power to impose safety conditions on constructed referable dams, regardless of whether or not the dam owner already has a development permit for the dam. The chief executive also has the power under s.492 to change those safety conditions. Safety conditions imposed or changed by the chief executive are taken to be part of a development permit approving the construction of the dam.

The Act also refers to the guidelines, which may be issued and used by the chief executive in the process of applying safety conditions to a referable dam. These guidelines are such guidelines and they apply to all referable dams in Queensland including all referable gully dams, hillside storages and ring tanks.

The *Queensland Dam Safety Management Guidelines* (NR&M 2002a) and the *Guidelines for Failure Impact Assessment of Water Dams* (NR&M 2002b) have already been issued by NRW and should be read in conjunction with these guidelines. In applying these guidelines, it should be noted, that they are intended to form the basis for safe practices and to provide a consistent approach in the assessment of the safety of referable dams in Queensland.

References to other guidelines issued by NRW are to be taken as a reference to any updated version of those guidelines where the context permits.

3 Methodology to determine Acceptable Flood Capacity

3.1 General

All referable dams are required to have sufficient flood discharge capacity to pass the following:

- (a) the Acceptable Flood Capacity without failure of the dam²
- (b) a Spillway Design Flood without any damage to the dam

Where the selected Spillway Design Flood discharge is less than the Acceptable Flood Capacity, the potential impacts of floods in excess of the Spillway Design Flood up to the magnitude of the Acceptable Flood Capacity shall be identified, quantified and documented in the written Acceptable Flood Capacity Assessment report (Appendix A). Such potential impacts shall include detailed assessments of:

- (a) how the magnitude of the adopted spillway design flood was determined and why it is considered acceptable
- (b) the probability of the floods greater than the spillway design flood occurring and the potential there is for damage and loss of life caused by such floods
- (c) the consequences of flows in excess of the spillway design flood and the impact of the higher flow velocities and greater water depths on various parts of the dam structure
- (d) the potential damage to the dam caused by these flows and how the energy from these flows is dissipated

When assessing the flood discharge capacity of existing dams, the existing flood discharge capacity shall be taken as the flood discharge capacity that can be discharged without failure of the dam in its current arrangement.

These *Guidelines on Acceptable Flood Capacity for Dams* are based on a range of ANCOLD and other guidelines as listed below:

- *Selection of Acceptable Flood Capacity for Dams* (ANCOLD, 2000a),
- *Assessment of the Consequences of Dam Failure* (ANCOLD, 2000b)
- *Risk Assessment* (ANCOLD, 2003)
- *Guide to Flood Estimation* (AR&R 1999, Nathan, R. J. and Weinmann, P.E).

As most of the processes from the relevant ANCOLD and AR&R 1999 guidelines are not repeated here, it is important that the above documents are read in conjunction with these guidelines. In particular, where issues are not specifically addressed in these NRW Guidelines on Acceptable Flood Capacity, the relevant sections of the referenced ANCOLD guidelines apply.

The combined inflows into the storage from all sources should be taken into account when assessing the required spillway capacity. This combined inflow should include all natural inflows as well as inflows from water harvesting and from diversion channels.

The combined discharge capacity of all spillways can be taken into account when assessing a dam's flood discharge capacity. However, unless it can be clearly demonstrated that outlet works or hydropower stations can be reliably operated during flood events, the discharge capacity of these structures is to be ignored when assessing discharge capacity during floods.

² Under the *Water Act 2000*, failure of a referable dam is defined as:

- (a) the physical collapse of all or part of the dam; or
- (b) the uncontrolled release of any of its contents.

When requested, a written Acceptable Flood Capacity Assessment Report must be prepared by a Registered Professional Engineer of Queensland (RPEQ) for the current dam arrangement and submitted to NRW. Appendix A outlines the requirements for the Acceptable Flood Capacity Assessment Report.

Dam owners should ensure that their dam can safely pass floods up to the Acceptable Flood Capacity. Also the following characteristics or features for the spillway and outlet works where appropriate should be demonstrated:

- (a) adequate resistance to erosion and cavitation
- (b) adequate wall height to retain the flows
- (c) adequate energy dissipation to prevent undermining or other erosion
- (d) adequate resistance to uplift and other hydraulic forces on the spillway during the passage of floods
- (e) capability to pass floating debris as required to ensure the unimpeded operation of the spillway
- (f) adequate safety from landslides and scour
- (g) adequate capacity to avoid restriction of the discharge capacity from debris build-up in the spillway approach channel and outlet channels.

In addition, where appropriate, the dam owner should ensure:

- (h) Spillway gates and other control devices will operate with sufficient flood discharge capacity under all design conditions.
- (i) Spillway gates, outlet works and other discharge control devices operate reliably. The reliability of discharge control operating mechanisms (including power supply, control and communication) should be commensurate with the hazard category involved and the time available during major floods to repair them or operate them by other means should problems occur. The reliability should be reflected in the determination of discharge capacity available to pass the Acceptable Flood Capacity.
- (j) Unless a case for a contrary view is adequately made, where fuse plugs or fuse gates are relied upon to pass the Acceptable Flood Capacity, they should be appropriately designed, constructed and maintained in order to fulfil their required function in accordance with the following:
 - Initial triggering of the fuse element is not to occur for floods having greater probability than 0.2 per cent AEP
 - Failure of successive fuse plugs or fuse gates is to be progressive, predictable and designed to minimise the impact on downstream Population at Risk (PAR);
 - The potential downstream impacts of fuse plug or fuse gate triggering at representative locations of PAR are to be identified and documented as part of the Acceptable Flood Capacity report (detailed in Appendix A).

Unless varied by the above, the design of fuse plugs is to comply with the provisions of US Department of the Interior (USBR 1987), *Guidelines for Using Fuse-plug Embankments in Auxiliary Spillways*.

- (k) Where stoplogs or flashboards are the primary discharge control mechanism, they are designed to:
 - be removed under conditions which overtop the stoplogs or flashboards, or

- be removed prior to the onset of any flood, or
- reliably fail under the flood loadings.

The spillway discharge capacity adopted for the Acceptable Flood Capacity Assessment Report should reflect the option adopted.

- (l) all components are designed to withstand the appropriate earthquake loadings³
- (m) assured access to all necessary locations on the dam for necessary operations during a flood event.
- (n) a discharge capacity that will not be compromised by the failure of any structure across the spillway, its approach channel or its outlet channel.

More details on each of the three assessment methods are provided below.

3.2 Small dams standard

This assessment method may be used for any referable dam in Queensland having:

- a zoned or relatively homogeneous earthen embankment less than 12 metres high
- a PAR of 15 or less
- uncontrolled spillways⁴
- depths of flooding of PAR of less than three metres and the product of the depth of flooding and the average flow velocity is less than 4.6 m²/sec.

It is expected that such levels of flooding are unlikely to occur for dams less than 12 metres high unless the discharge is severely concentrated in downstream channels or where the PAR is located in very close proximity to the dam.

This method is also not to be used for dams relying on spillways controlled by gates or other mechanical discharge control structures to pass the Acceptable Flood Capacity. For dams outside the parameters described above, only the fall-back option or the risk assessment procedure should be used.

The following steps are to be applied in the small dams standard assessment process:

1. Determine the maximum incremental PAR for any potential dam failure condition by following the procedures outlined in the *Guidelines for Failure Impact Assessment of Water Dams* (NR&M, 2002b) for a range of flood failure conditions up to the 1:20 000 Annual Exceedance Probability (AEP) flood event.

Note: If the incremental PAR is greater than 15 for any of the flood failure conditions, this ‘small dams standard’ cannot be used to determine the AFC and one of the other methods must be used.

2. Determine the AEP of the required Acceptable Flood Capacity rainfall event by applying the maximum PAR to the graph presented in Figure 1:

$$AEP = \left(\frac{1}{PAR} \right) \times 10^{-3}$$

³ Until a Queensland guideline is developed on earthquake loadings for referable dams, the *ANCOLD “Guidelines for Design of Dams for Earthquake”, August 1998* (ANCOLD 1998) should be applied.

⁴ In this context, an ‘uncontrolled spillway’ is one which does not rely on flow through spillway gates or other mechanical discharge control structures to pass the Acceptable Flood Capacity.

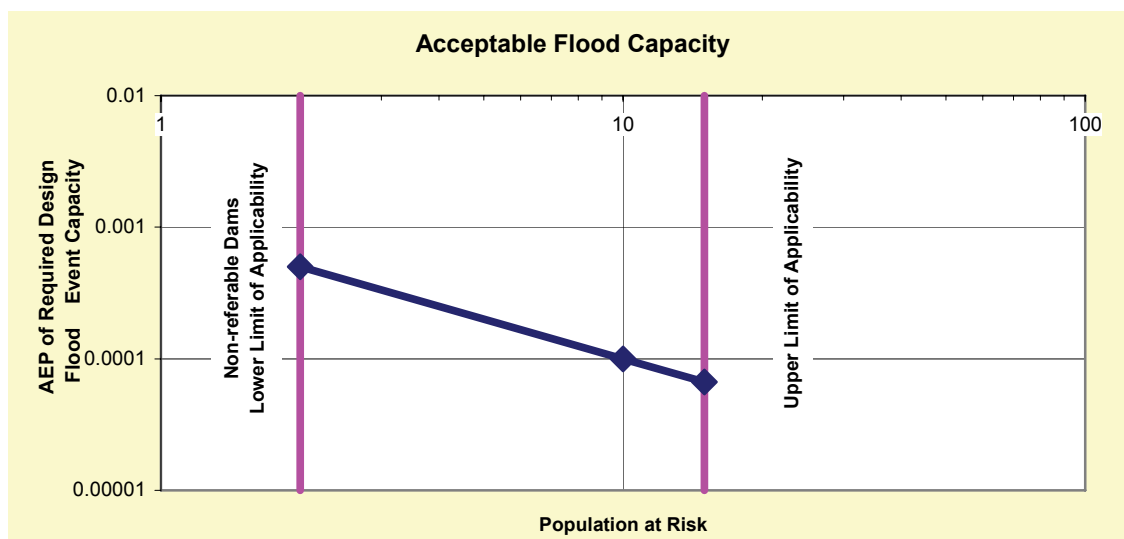


Figure 1 Acceptable flood capacity standard for small dams

3. Determine the storage inflow hydrograph for the critical duration storm event commensurate with the AEP of the design flood event rainfall as determined in Figure 1 (Refer Section 3.5);
4. Route this flood through the dam.

Note that it is to be assumed that the dam storage is initially at Full Supply Level (FSL) at the start of the flood event.

The required Acceptable Flood Capacity (AFC) for the dam is the discharge capacity required to pass the critical duration storm event without causing failure of the dam.

Note that this option does not take into account:

- (a) Any differentiation between new and existing dams;
- (b) Financial, business, social or environmental damages that might occur as a result of any potential failure;
- (c) The ALARP principle.

This small dams standard is a simplified version of the fall-back option assessment process and as such, should be less costly to undertake than either of the alternative methods. However, small dam owners must be aware that they could benefit by carrying out one of the other more detailed assessment methods by perhaps demonstrating that a lower flood discharge capacity is appropriate for their dam.

3.3 Fall-back option

Except as modified in these guidelines, the following documents should be adopted and used for this method:

- ANCOLD *Guidelines on Selection of Acceptable Flood Capacity for Dams* (ANCOLD 2000a);
- ANCOLD *Guidelines on Assessment of the Consequences of Dam Failure* (ANCOLD 2000b); and
- NRW *Guidelines for Failure Impact Assessment of Water Dams* (NRM, 2002b).

The following steps are to be applied to the fall-back option assessment process:

1. Conduct an assessment of the potential consequences of dam failure associated with the passage of a range of design floods through the storage using the consequence criteria contained in the ANCOLD *Guidelines on Assessment of the Consequences of Dam Failure* (ANCOLD, 2000b) and the following qualifications:
 - The dam is to be assumed to be initially at Full Supply Level at the start of the flood event;
 - Breach dimensions, timing and PAR are to be determined in accordance with the NRW *Guidelines for Failure Impact Assessment of Water Dams* (NR&M, 2002b).
2. Determine the Hazard Category rating for the dam for each case in accordance with Table 1:

Incremental Population at Risk (PAR)	Severity of Damage and Loss			
	Negligible	Minor	Medium	Major
$2 \leq \text{PAR} \leq 10$	Low Notes 1	Significant Note 5	Significant Note 5	High C Note 6
$10 < \text{PAR} \leq 100$	Note 1	Significant Notes 2 and 5	High C Note 6	High B Note 6
$100 < \text{PAR} \leq 1000$		Note 2	High A Note 6	High A Note 6
$\text{PAR} > 1000$			Note 3	Extreme Note 6

Table 1: Hazard Category for Referable Dams

(Please Note: Table 1 is a modified version of Table 3 Hazard Categories in the, Guidelines on Assessment of the Consequences of Dam failure (ANCOLD, 2000b.)

Note 1: It is unlikely that the severity of damage and loss will be “Negligible where one or more houses are damaged.

Note 2: Minor damage and loss would be unlikely when PAR exceeds 10.

Note 3: Medium damage and loss would be unlikely when the PAR exceeds 1000.

Note 4: Not used.

Note 5: Change to High C where there is the potential for one or more lives being lost.

Note 6: See section 2.7 and 1.6 in the Guidelines on Assessment of the Consequences of Dam failure (ANCOLD, 2000b) for an explanation of the range of High Hazard Categories.

3. Identify the required range of the Annual Exceedence Probability (AEP) flood for the dam in accordance with Table 2 [based on Table 8.1 in the *Guidelines on Selection of Acceptable Flood Capacity for Dams* (ANCOLD, 2000a)]:

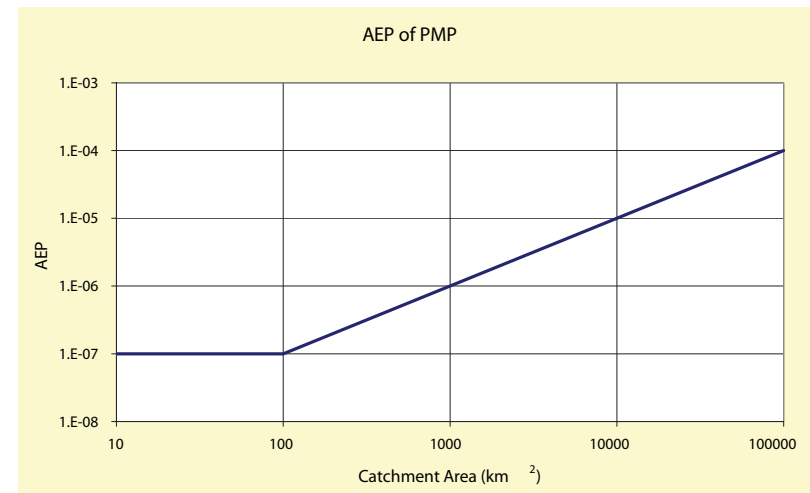
Incremental Population at Risk (PAR)	Severity of Damage and Loss								
	Negligible		Minor		Medium		Major		
$2 \leq PAR \leq 10$		5.0×10^{-4}		5.0×10^{-4}		1.0×10^{-4}		1.0×10^{-5}	
	Low		Significant		Significant		High C		
$10 < PAR \leq 100$		5.0×10^{-4}		1.0×10^{-4}		1.0×10^{-4}		C	
			Significant		High C		High B		
$100 < PAR \leq 1000$		1.0×10^{-4}		1.0×10^{-4}		C	B	B	
					A	A	A	A	
$PAR > 1000$	If in this region, go to the next highest severity of Damage and Loss category for the same PAR								
						PMF		PMF	
							Extreme		
						PMF		PMF	

Where

- A = PMP Design Flood
- B = PMP Design Flood or 10^{-6} , whichever is the smaller flood event
- C = PMP Design Flood or 10^{-5} whichever is the smaller flood event

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

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



4. Interpolate (using the procedure defined in Appendix C) within the nominated range to determine the required Annual Exceedence Probability (AEP) for the spillway design flood for each failure case.
5. Determine the required AEP of the “critical duration design flood event rainfall” by selecting the flood event having the lowest AEP in Step 4.
6. Determine the storage inflow hydrograph for the critical duration design flood event commensurate with the AEP of the design flood event rainfall (Refer Section 3.5).

Note that it is to be assumed that the dam reservoir is initially at Full Supply Level at the start of the flood event.

The required Acceptable Flood Capacity (AFC) is the discharge capacity required to pass the critical duration storm event without causing failure of the dam.

Note: The owner of the dam should be aware that the fall-back method may result in a higher design requirement and consequent higher cost of the upgrade required to bring it up to the required standard than the alternative risk assessment procedure (incorporating ALARP).

3.4 Risk assessment procedure

Except as modified in these guidelines, the Acceptable Flood Capacity Assessment based on the risk assessment procedure should be carried out in accordance the following guidelines:

- *ANCOLD Guidelines on Selection of Acceptable Flood Capacity for Dams* (ANCOLD, 2000a)
- *ANCOLD Guidelines on Assessment of the Consequences of Dam failure* (ANCOLD, 2000b)
- *NRW Guidelines for Failure Impact Assessment of Water Dams* (NR&M 2002b) (for the dam breach sizes and timings and the estimation of Population at Risk);
- *ANCOLD Guidelines on Risk Assessment* (ANCOLD, 2003) (with particular attention to the quantitative studies at advanced or very advanced levels).

A design life of no less than 150 years following the completion of any necessary dam safety upgrades is to be adopted when assessing the risk of failure over the life of the dam. Note that the probability of exceedence of an event over the design life is **not** simply the AEP times the life of the dam. It is calculated using the formula:

$$\text{Probability over design life} = 1 - (1 - \text{AEP})^{\text{design life}}$$

The following steps are to be applied to the Risk Assessment Procedure:

1. Conduct a comprehensive, quantitative risk assessment study of the dam for all loads and consequences in accordance with the *ANCOLD Guidelines on Risk Assessment*, (ANCOLD 2003), and *Guidelines on Selection of Acceptable Flood Capacity for Dams*, (ANCOLD, 2000a). Details on the probability of flood events causing dam failure, based on the probability of the event over the life of dam and expected loss of life during these events must be reported in the Acceptable Flood Capacity assessment report. The following general qualifications apply:
 - As the potential for loss of life increases, the greater degree of rigour and thoroughness will be expected in the risk assessment.

- Dam is to be initially at Full Supply Level at the start of any flood events.⁵
- Breach dimensions and timing are determined in accordance with *Guidelines for Failure Impact Assessment of Water Dams* (NR&M, 2002b)
- Total PAR is estimated using the procedures contained in the NRW *Guidelines for Failure Impact Assessment of Water Dams* (NR&M, 2002b) or ANCOLD, *Guidelines on Assessment of the Consequences of Dam Failure* (ANCOLD, 2000b);
- *Graham's Method* (Graham, 1999) is to be used for estimating loss of life (LOL) due to dam break flood events. Unless it can be clearly demonstrated that warnings will be reliably issued and disseminated around the impacted community at least 12 hours prior to the anticipated impact of dam failure, it is to be assumed that no warning is available to the Population at Risk for dam failure events⁶.
- Note that *Graham's Method* for estimating Loss of Life (LOL) during a dam break event is based on the total population at risk rather than the incremental population at risk produced by the *Guidelines for Failure Impact Assessment of Water Dams* (NR&M, 2002b). It is also significant that the 'flood severity' also tends to be greater with dam break. Unless it can be clearly demonstrated that fewer people will be exposed to any dam break flood discharge, the total PAR is to be used in assessments of potential loss of life due to the failure event. Thus the estimated incremental loss of life due to failure should be taken as:

$$\begin{aligned} \text{Incremental LOL} &= (\text{LOL for flood event with dam failure}) \text{ less} \\ \text{due to failure event} & \quad (\text{LOL for same event without dam failure}) \end{aligned}$$

- Note that the LOL for flood events without dam failure is not covered by *Graham's Method* but is typically in the range 0.001xPAR to 0.0001xPAR. This means that the Incremental LOL can, in most circumstances, be taken as the total LOL due to dam break.
2. Use the risk assessment study data on the annual probabilities of dam failure and estimated LOL to determine whether the risk profile is within ANCOLD's recommended 'limits of tolerability'. These minimum limits of tolerability are reproduced below from the section on 'Life safety risks' in the ANCOLD *Guidelines on Risk Assessment* (ANCOLD, 2003):-
- *for existing dams, an individual risk to the person or group, which is most at risk, that is higher than 10⁻⁴ per annum is unacceptable, except in exceptional circumstances*
 - *for new dams or major augmentations of existing dams, an individual risk to the person or group, which is most at risk, that is higher than 10⁻⁵ per annum is unacceptable, except in exceptional circumstances*
 - *for existing dams, a societal risk that is higher than the limit curve, shown on Fig. 7.4 [of ANCOLD, Guidelines on Risk Assessment] is unacceptable, except in exceptional circumstances*
 - *for new dams or major augmentations of existing dams, a societal risk that is higher than the limit curve, shown on Fig. 7.5 [of ANCOLD, Guidelines on Risk Assessment], is unacceptable, except in exceptional circumstances.*

⁵ It is recognised that this restriction is conservative. However, anecdotal evidence suggests that there is a higher likelihood of large rainfall events occurring towards the end of a 'wet' wet season. The assumption of the dam initially at Full Supply Level is to apply unless dam owners can clearly demonstrate, to the satisfaction of the chief executive, that an alternative approach is appropriate.

⁶ In making the case for a shorter warning time, the dam owner will need to demonstrate that a reliable warning will be able to be given under all reasonable circumstances that can be effectively and efficiently disseminated to the affected PAR and that suitable arrangements are in place to ensure that this will not reduce in effectiveness with the passage of time.

3. If the risk profile for the existing dam is above the limits of tolerability:
 - (a) determine the storage inflow hydrograph for the critical duration design flood event commensurate with the AEP of the design flood event rainfall which just satisfies the limits of risk tolerability assuming the dam is in its current arrangement (Refer Section 3.5). As the Risk Assessment Procedure involves integration of all hazards including flood events, the risk analyst must be aware of the failure modes when evaluating the flood AEP, particularly where failure modes not directly associated with spillway flood discharge capacity are significant contributors to the risk i.e. piping;
 - (b) formulate risk reduction options that would bring the risk profile down to the limit of tolerability.
4. Assess compliance with the ALARP principle by formulating additional risk reduction options that would bring the risk profile further below the limit of tolerability and undertaking a cost-benefit analysis for the upgrade options required to reduce the risk profile below the limits of tolerability based on:
 - incremental project costs and benefits to reduce the risk profile beyond the limits of tolerability. (Only include those costs considered necessary and sufficient to implement the measures to further reduce risk)
 - the cost-benefit methodology detailed in Appendix B;
 - a Value of a Statistical Life (VOSL) of \$5 million (in 2004 dollars)⁷.

The options considered should be sufficient to clearly demonstrate that the ALARP criteria have been satisfied. In this context ALARP is considered to be satisfied whenever the incremental cost of undertaking a spillway upgrade project to reduce the risk below the specified limits of tolerability exceeds the benefits.
5. The spillway flood discharge capacity required to satisfy the limits of tolerability including ALARP is to be considered the Acceptable Flood Capacity (AFC).

Note that in some circumstances where the flood risk is only a relatively minor part of the overall risk profile for the dam, other dam safety remedial works may be required to reduce the risk profile below the limits of tolerability.
6. Determine the relative proportion (as a percentage) of the inflow flood determined in Step 5 above that can be passed by the existing dam.

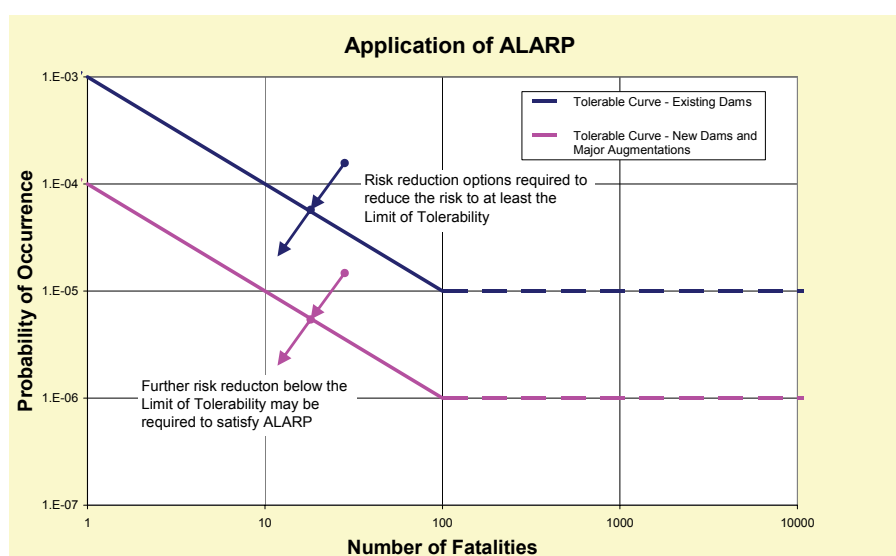


Figure 2 Application of ALARP to bring societal risk profile below Limit of Tolerability

⁷ Note: Because of differences in the methodologies, the VOSL is not directly comparable with the ANCOLD Cost to Save a Statistical Life (CSSL)

3.5 Estimation of the critical duration storm event

The following process is generic for deriving the critical storm duration hydrograph and is to be used for estimating the critical duration inflow flood hydrographs for a given Annual Exceedence Probability (AEP) for all Acceptable Flood Capacity (AFC) assessment options.

- (a) Determine the rainfall for a range of storm durations at the given AEP appropriate for the dam catchment and dam configuration. The required rainfall shall be estimated by applying, as appropriate:
 - *CRC Forge method* (refer to the NR&M report *Extreme Rainfall Estimation Project (Hargraves, 2004)* for assessing probabilities for “rare” flood events (Note: flood probabilities are to be based on the probabilities of the causative rainfall events) and
 - Appropriate methodology for assessing Probable Maximum Precipitation (PMP), in accordance with:
 - the Bureau of Meteorology (BoM) Bulletin 53 *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method* (GSDM, BoM, 2003a), or
 - the BoM *Revision of the Generalised Tropical Storm method for Estimating Probable Maximum Precipitation* (GTSMR, BoM 2003b).
 - The provisions of *Australian Rainfall and Run-off* (AR&R 1999) shall be used for interpolating rainfall magnitudes between the CRC Forge rainfalls and the PMPs.
- (b) The runoff from this rainfall is to be converted into inflow flood hydrographs using a non-linear run-off routing model (such as RORB, WBNM, RAFTS etc). Where reasonable calibration data is available, the model should be calibrated but with calibrations biased towards larger flows. Where reasonable calibration data is not available, the regional parameters approach presented in the Institution of *Engineers Australia, Book VI—Estimation of Large to Extreme Floods* (Nathan & Weinmann, 1999) should be applied.

All catchments are to be assumed in a saturated condition prior to the start of the storm event causing the rainfall. Unless the case for different loss models is appropriately made, an “initial loss-continuing loss” model is to be applied. Unless an effective case can be made to use other loss parameters, the initial loss/continuing loss parameters recommended in *Book VI of Australian Rainfall and Run-off—Volume 1* (AR&R 1999) are to be used.

When assessing the inflow hydrographs of flow into the dam reservoir during a flood event, all inflows into the storage should be considered. This should include any inflows from water harvesting pumps or run-off from catchments diverted into the storage. This will produce inflow hydrographs into the dam reservoir of the type shown in Figure 3.

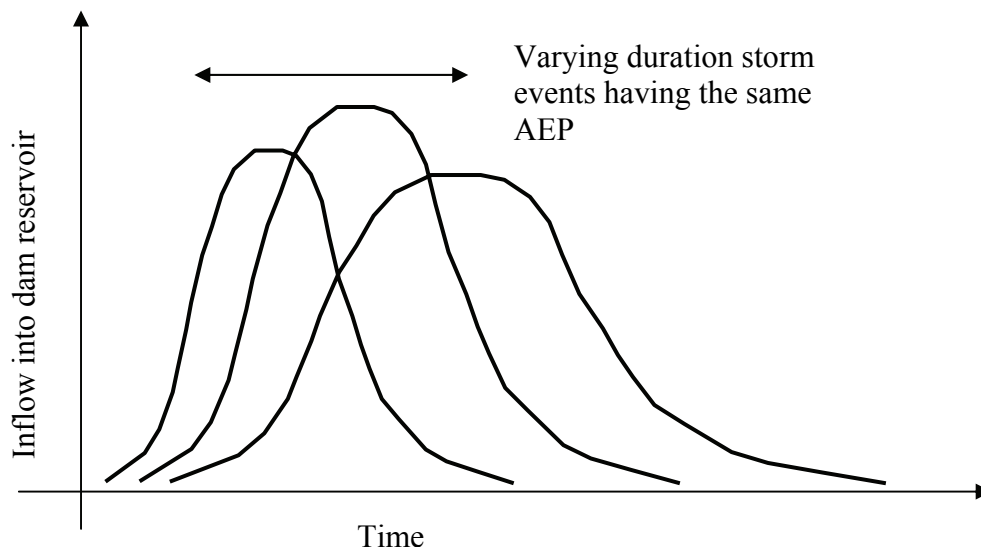


Figure 3 - Effect of storm durations on flood magnitude

- (c) Route this run-off through the reservoir storage to determine the resultant maximum reservoir headwater and corresponding outflow from the dam storage for each flood event. Estimates of outflows during floods are to be based on the following assumptions:
- The reservoir is to be at Full Supply Level at the start of the flood event or sequence of flood events.
 - Where the dam wall is designed to accommodate discharge over the non-overflow sections (e.g. as in some mass concrete dams), the analysis can take this discharge into account. However, if they are not designed to accommodate discharge (e.g. earth dam embankments), it is to be assumed that the existing spillway walls extend vertically upward to the height required to pass the discharge.
 - When assessing the outflow for spillways controlled by spillway gates or other mechanical discharge control devices, the assumed reservoir operations are to be based on normal flood operational procedures for the dam together with:
 - i. for assessments using the Fall-back option, the failure of at least 16 per cent of gates or other discharge devices (rounded up to the nearest whole number of gates) from the start of the event
 - ii. for assessments using the Risk Assessment procedure the person doing the assessment should assess the probability of gate failure using the best available information.
- (d) The result of steps (a) to (c) will be a series of ‘Reservoir Level versus Time’ curves as shown in Figure 4.
- (e) Select the flood event producing the maximum reservoir level as the critical duration flood event for the dam.

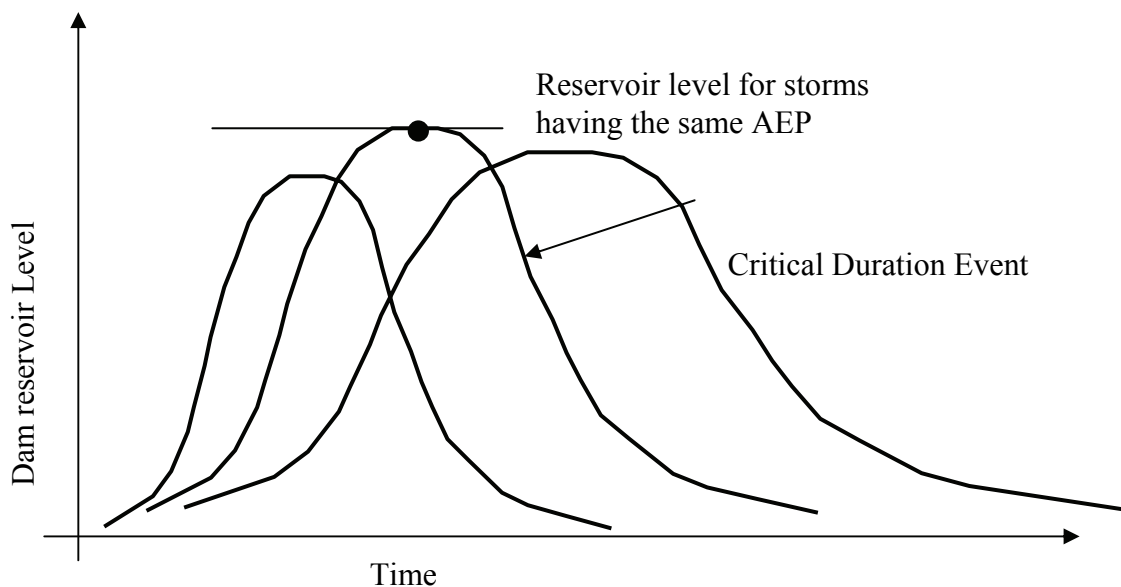


Figure 4 Selection of Critical Duration Flood Event

3.6 Freeboard

Freeboard should be provided above maximum flood levels for wind set-up and wave run-up. It should be noted that freeboard can be a significant component of any Acceptable Flood Capacity Assessment with considerations of the need for freeboard provisions being more critical for embankment dams, as such dams are generally more susceptible to breaching and failure by overtopping.

The magnitude of any necessary freeboard will vary for each dam and will depend on issues such as the :

- effective resistance to dam structure to waves and overtopping
- magnitude and direction of winds and the effective fetch for winds generated waves
- depth of the storage
- likely duration of headwater levels near the crest of the dam and the likely coincidence of these high flood levels with strong winds
- potential settlement of the crest of embankment dams.

The magnitude of wind set-up and wave run-up should be estimated using appropriate Australian wind data and the processes outlined in US Department of the Interior, Bureau of Reclamation, *Freeboard Criteria and Guidelines for Computing Freeboard Allowances for Storage Dams* (USBR 1981).

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

- developments in meteorology and estimates of extreme rainfalls
- developments in hydrologic methodology and estimated floods
- the potential for future developments downstream requiring additional flood discharge capacity
- the generally low incremental cost of providing additional flood discharge capacity at the time of initial construction.

Concrete dams can sometimes tolerate the increased loading associated with some overtopping, and as such, may not require positive freeboard. Additionally, in some cases, concrete dams can accept a negative freeboard, which is some degree of overtopping. Items that need to be considered when assessing the required freeboard on concrete dams include the impact of the maximum reservoir headwater levels on the dam structure and the potential for scour of the toe of the dam or the abutments, which could affect stability.

For embankment dams, freeboard provision can alternatively be considered as an integral part of the risk assessment procedure.

Consideration may be given to minimal freeboard 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 duration and resistance to potential overtopping due to wind set-up and wave run-up and high headwater levels.

Provisions proposed for freeboard and the associated Acceptable Flood Capacity and relevant AEP shall be indicated in written Acceptable Flood Capacity Assessment reports produced in accordance with Appendix A.

4 Upgrade schedules

The required Acceptable Flood Capacity for a particular referable dam is the capacity required to safely discharge the Acceptable Flood Capacity as determined through risk assessment or other methods outlined in these guidelines and dam safety conditions and approved by the regulator. This capacity will be different for each dam and will depend on the individual circumstances of each dam. Dam owners should note that the required flood discharge capacity may change with time as changes to land use occur downstream of the dam.

All new referable dams will be required to provide a total discharge capacity equal to the Acceptable Flood Capacity from the time they become operational or start to permanently store water.

Owners of existing referable dams, which cannot safely discharge the Acceptable Flood Capacity, will be required to upgrade the spillway capacity of their dams. The timing of any necessary upgrade works for the dam is dependent on the proportion of the Acceptable Flood Capacity able to be safely passed by the existing dam. The timing will have to at least satisfy the schedule presented in Table 3.

The procedure to be adopted for determining the proportion of the Acceptable Flood Capacity able to be passed by the existing spillway(s) is as follows:

- (a) The discharge values of the critical duration storm event inflow hydrograph are scaled by a factor 'k' to produce a 'trial' flood event such that

$$Q_{\text{trial}} = k Q_{\text{cdse}}$$

where Q_{trial} = The discharge ordinate of the trial flood event

Q_{cdse} = Inflow ordinate of the critical duration storm event producing the Acceptable Flood Capacity discharge

k = the proportion of the Acceptable Flood Capacity

The 'time base' for the trial inflow hydrograph remains unaltered.

- (b) The resultant flood is then routed through the storage to determine the maximum headwater level in the reservoir.
- (c) Steps (a) and (b) are repeated with new estimates of 'k' until
 - i. for cases where the Acceptable Flood Capacity is determined by the Small Dam Standard or the 'Fall-back option: Where the maximum headwater level in the storage just reaches the dam crest or some other level below the dam crest at which failure of the dam would be likely⁸.
 - ii. for cases where the Acceptable Flood Capacity is determined by the Risk Assessment Procedure: Where the risk profile just satisfies the limits of tolerability and the ALARP criteria.

This proportion of the Acceptable Flood Capacity is taken to be the discharge capacity of the existing dam.

⁸ Unless a dam embankment is specifically designed to be overtopped safely, the level at which failure is to be considered 'likely' is to be no higher than the level of the embankment crest. If defects are known to be present in embankment dams which could cause failure when the water level is below the level of the embankment crest, this lower level is to be taken as the 'maximum headwater level'. For dams assessed as being capable of being safely overtopped, this level of overtopping can be taken into account when determining 'maximum headwater level'. When considering the combined impact of wind set-up and waves on top of high reservoir levels due to flooding, the Annual Exceedence Probability of the overall event is to be the combined probability of the flood causing the headwater levels and the probability of the wind event generating the set-up and the waves. Wind set-up and wave heights are to be determined using appropriate Australian wind data and the processes contained in US Department of the Interior, Bureau of Reclamation, *Freeboard Criteria and Guidelines for Computing Freeboard Allowances for Storage Dams* (USBR, 1981).

Note that although consideration of the current consequences would be sufficient for this assessment, it is strongly recommended that likely future downstream developments be taken into account in assessing AFC.

The programming of any necessary dam safety upgrade works is to take into account, factors such as the time necessary to complete the work and the time of year available to undertake the work so as to minimise any additional risk to those living downstream.

Dam owners may choose to stage spillway upgrades to meet these timeframes, or to undertake all required works to meet 100 per cent of the required spillway capacity in one stage.

Tranche	Required minimum flood discharge capacity	Date by which the required minimum flood capacity is to be in place for existing dams
1	25% of AFC or 1:500 AEP flood event (whichever is the bigger flood)	These dams must be upgraded as soon as possible ¹
2	50% of AFC or 1:2000 AEP flood event (whichever is the bigger flood)	1 October 2015 ^{2,3}
3	75% of AFC	1 October 2025 ^{2,3}
4	100% of AFC	1 October 2035 ^{2,3}

Table 3: Schedule for Dam Safety Upgrades

Notes to Table

1. As a guide, it is expected that up to about five years may be required to complete a flood discharge capacity upgrade for dams greater than 10 meters in height, and two years will be required to complete a spillway upgrade for smaller dams. However, each case will be considered on its own merits.
2. In each case the required discharge capacity will need to be reassessed just prior to the undertaking of final spillway upgrade works to ensure that the required Acceptable Flood Capacity has not changed and that the planned spillway capacity is still consistent with the specified upgrade program.
3. The timing of the tranches 2, 3 and 4 will be confirmed once the Acceptable Flood Capacity, and related, assessments have been completed for all or most of the known referable dams. This is anticipated to occur by 1 July 2008.

5 Glossary

Please note: This is a selected glossary only. Please refer to the Glossary in the various ANCOLD Guidelines for a more comprehensive definition of all terms.

AEP - Annual Exceedance Probability – The probability that a particular flood value will be exceeded in any one year.

AFC - Acceptable Flood Capacity - The overall flood discharge capacity required of a dam determined in accordance with these guidelines including freeboard as relevant, which is required to pass the critical duration storm event without causing failure of the dam.

ALARP – As Low As Reasonably Practicable principle, which states that risks, lower than the limit of tolerability, are tolerable only if risk reduction is impracticable or if its cost is grossly disproportionate (depending on the level of risk) to the improvement gained.

ANCOLD - Australian National Committee on Large Dams

AR&R 99 – In the context of this paper it refers to ‘Australian Rainfall and Runoff, A guide to Flood Estimation, Book VI, Estimation of Large to Extreme Floods’, 1999.

BoM – Commonwealth Bureau of Meteorology

CRCForge – Co-operative Research Centre Focussed Rainfall Growth Estimation – A regional frequency analysis technique used to derive estimates of large to rare rainfall (see Section 3.5).

Critical Duration Design Flood Event – The design flood event having a duration which causes the maximum discharge from a dam for a given Annual Exceedance Probability.

DCF - Dam Crest Flood – the flood event which, when routed through the storage with the storage initially at Full Supply Level, results in still water in the storage, excluding wind and wave effects which:

- for an embankment dam, is the lowest point of the embankment crest,
- for a concrete dam, is the level of the non-overflow section of the dam, excluding handrails and parapets if they do not store water against them;
- for a concrete faced rockfill dam, is the lowest point of the crest structure or a point on a wave wall if it is designed to take the corresponding water load.

Dam Break Flood – The flood event occurring as a consequence of dam failure.

Dam failure is the physical collapse of all or part of a dam or the uncontrolled release of any of its contents.

Design Life – The useful life for which a structure is designed.

EAP – Emergency Action Plan (prepared and implemented in accordance with requirements of *Queensland Dam Safety Management Guidelines* (NR&M, 2002a)

Failure Mode – A way that failure can occur, described by a means by which element or component failures must occur to cause loss of the sub-system or system function.

Fall-back option – is the assessment methodology described in Section 3.2 of these guidelines.

Fatality rate - is the appropriate fatality rate in Graham’s loss of life formula (Graham, 1999).

FIA - Failure Impact Assessment undertaken and certified in accordance with the requirements of the Water Act 2000 and NR&M’s *Guidelines for Failure Impact Assessment of Water Dams* (NR&M 2002b).

Flood Discharge Capacity – The capacity to discharge floods (in m³/sec)

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”.

FSL – Full Supply Level – The level of the water surface when the water storage is at maximum operating level, when not affected by flood.

Fuse plugs (and fuse gates) – Discharge elements designed to fail in a controlled fashion once a design event has been triggered (see Section 3.1).

Graham’s Method – A method for estimating the loss of life due to dam failure (refer to Section 3.4)

Height (of dam) – means the measurement of the difference in level between the natural bed of the watercourse at the downstream toe of the dam or, if the dam is not across a watercourse, between the lowest elevation of the outside limit of the dam and the top of the dam.

Hydrograph - A graphical representation of a time-discharge curve of the unsteady flow of water.

Hazard Category – The potential incremental losses and damages directly attributable to the failure of the dam.

Incremental PAR – refer to PAR.

Limits of Tolerability – A risk that society can tolerate so as to secure certain net benefits (refer to Section 3.4)

LOL - Loss of Life - means the estimated loss of life in the event of a dam failure.

NRW – The Queensland Department of Natural Resources & Water (previously known as the Department of Natural Resources & Mines or NR&M or the Department of Natural Resources, Mines and Water or NRMW).

Outlet Works – A combination of structures and equipment required for the safe operation and control of water released from a reservoir to serve various purposes, e.g. regulate stream flow and quality; provide irrigation, municipal, and/or industrial water.

PAR - Population at Risk – means the number of persons, calculated under the guidelines referred to in s.482 (I) (b) [of the Water Act 2000], whose safety will be at risk if the dam, or the proposed dam after its construction, fails. Unless otherwise indicated, PAR is the ‘incremental PAR’ due to the failure event i.e. the difference in the PAR for the same event with dam failure relative to the event without dam failure. When ‘Total PAR’ is referred to, this is the total PAR inundated both due to the natural flood event and the natural flood levels aggravated by the failure event.

PMP Design Flood – The flood resulting from the PMP using AEP neutral assumptions of catchment conditions.

PMF - Probable Maximum Flood – The flood resulting from PMP, and where applicable snow melt, coupled with the worst flood-producing catchment conditions that can be realistically expected in the prevailing meteorological conditions.

PMP - Probable Maximum Precipitation – The theoretical greatest depth of precipitation for a given duration that is physically possible over a particular catchment area, based on generalised methods.

Probability of Occurrence – The probability that the risk (event) will occur.

Referable Dam – A dam, or a proposed dam for which:

- (a) a failure impact assessment is required to be carried out [under the Water Act 2000]; and
- (b) the assessment states the dam has, or the proposed dam after its construction will have, a category 1 or category 2 failure impact rating; and
- (c) the chief executive has, under section 487 [of the Water Act 2000], accepted the assessment.

The following are not referable dams:

- (a) a dam containing, or a proposed dam that after its construction will contain, hazardous waste.
- (b) a weir, unless the weir has a variable flow control structure on the crest of the weir.

The following are not dams and cannot therefore be referable dams:

- (a) a rainwater tank;
- (b) a water tank constructed of steel or concrete or a combination of steel and concrete;
- (c) a water tank constructed of fibreglass, plastic or similar material.

Ring tank – A dam that has a catchment area that is less than 3 times its maximum surface area at full supply level.

Risk Assessment Procedure – is the assessment methodology described in Section 3.4 of these guidelines.

Risk Profile - The aggregated relationship between the consequences resulting from a range of adverse events and their probability of occurrence (see Section 3.4).

RPEQ – A Registered Professional Engineer of Queensland as defined under the Queensland Professional Engineers Act 2002.

Small Dams Standard – is the assessment methodology described in Section 3.2 of these guidelines.

Societal Discount Rate – The discount rate used in determining the net present value (refer to Appendix B)

Societal Risk – The risk of widespread or large scale detriment and multiple loss of life from the realisation of a defined hazard. Refer also to the definition in *ANCOLD Guidelines on Risk Assessment* (ANCOLD, 2003)

Spillway – A weir, channel, conduit, tunnel, gate or other structure, designed to permit discharges from the reservoir when pondage levels rise above FSL; can include secondary, auxiliary, emergency spillways or fuse plugs.

Spillway Design Flood – The flood event which can be routed through the dam (with appropriate allowance for freeboard due to wind and wave effects) without any damage to individual sections of the dam.

Sunny Day Failure - means a dam failure which is not significantly affected by a natural flood occurring at the same time.

VOSL - Value of Statistical Life

Weir - A barrier constructed across a watercourse below the banks of the watercourse that hinders or obstructs the flow of water in the watercourse.

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