Guidelines on Acceptable Flood Capacity for Dams

February 2007

Contents

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 Queensland[1].

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.

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[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 dam[2]

(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.

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[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 loadings[3]

(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 spillways[4]

- 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 m^2/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:

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

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[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.

Acceptable Flood Capacity
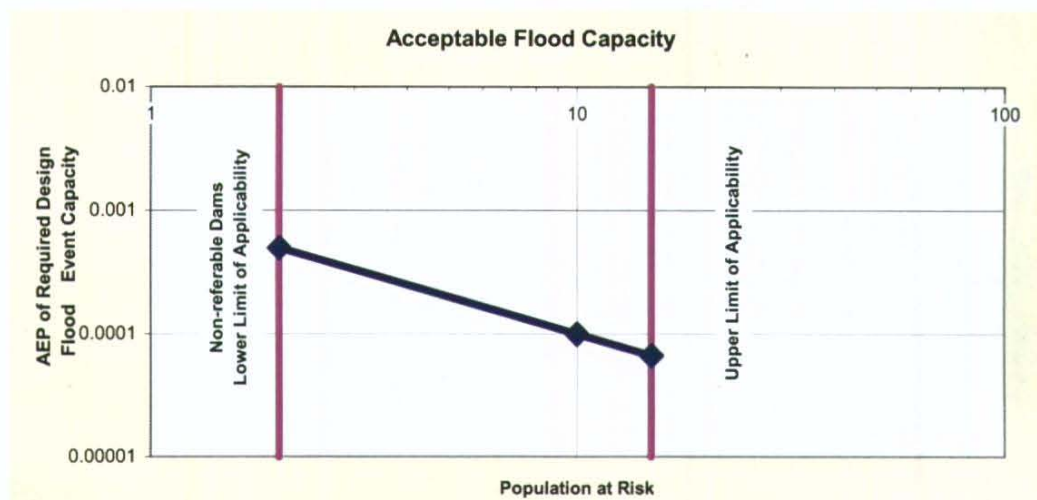
Figure 1 Acceptable flood capacity standard for small dams

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
$2 \le PAR \le 10$	Low Notes 1	Significant Note 5	Significant Note 5	High C Note 6
$10 < PAR \le 100$		Significant Notes 2 and 5	High C Note 6	High B Note 6
$100 < PAR \le 1000$	Note 1	Note 2	High A Note 6	High A Note 6
$PAR > 1000$			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
$2 \le PAR \le 10$	Low 5.0×10^{-4} 5.0×10^{-4}	Significant 5.0×10^{-4} 1.0×10^{-4}	Significant 1.0×10^{-4} 1.0×10^{-4}	High C 1.0×10^{-5} C
$10 < PAR \le 100$	5.0×10^{-4}	Significant 1.0×10^{-4}	High C 1.0×10^{-4}	High B 1.0×10^{-5}
	1.0×10^{-4}	1.0×10^{-4} C	C B	B
$100 < PAR \le 1000$	If in this region, go to the next highest severity of Damage and Loss category for the same PAR	A	High A A	High A A
		A	A	A
$PAR > 1000$			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

AEP of PMP
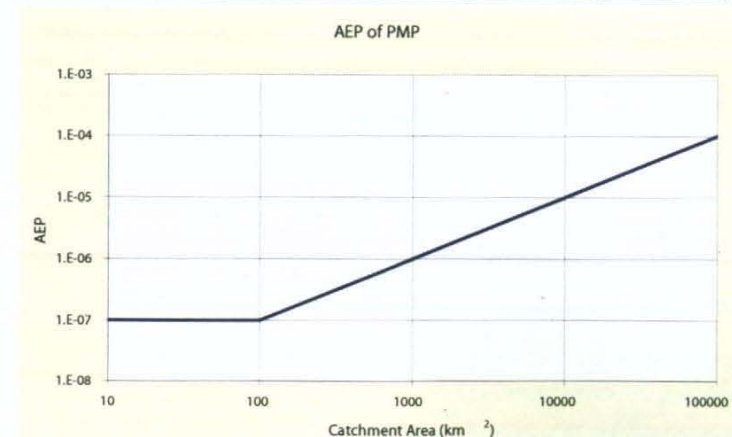
4. Interpolate (using the procedure defined in Appendix C) within the nominated range to determine the required Annual Exceedence Probability (AEP) for the spillway design flood for each failure case.

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 events[6].

- 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:

$$\frac{Incremental\,LOL}{due\,to\,failure\,event} = \frac{(LOL\,for\,flood\,event\,with\,dam\,failure)\quad less}{(LOL\,for\,same\,event\,without\,dam\,failure)}$$

- 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.*

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[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.

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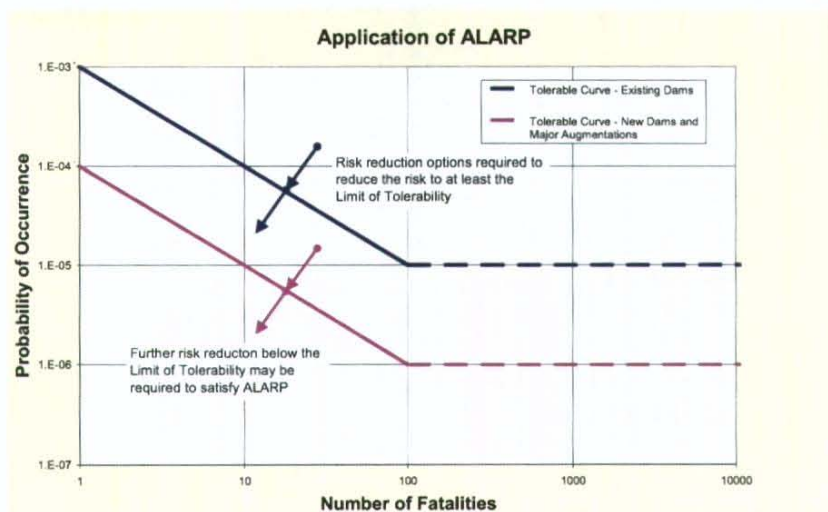
Figure 2 Application of ALARP to bring societal risk profile below Limit of Tolerability

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[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:

  o the Bureau of Meteorology (BoM) Bulletin 53 *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method* (GSDM, BoM, 2003a), or

  o 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.
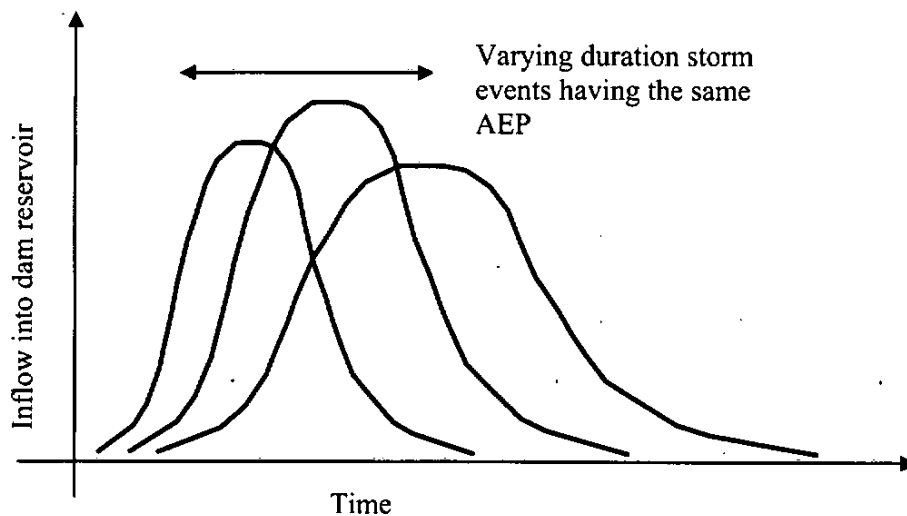
Figure 3 - Effect of storm durations on flood magnitude

(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.

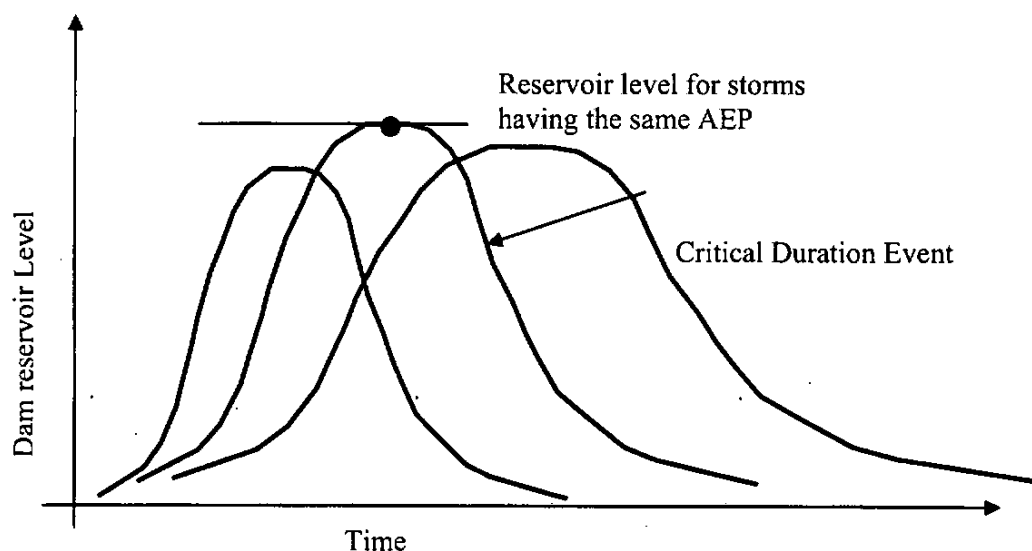(e) Select the flood event producing the maximum reservoir level as the critical duration flood event for the dam.

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

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

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 likely[8].

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.

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[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 Exceedence 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.

6 References

ANCOLD 1998, Australian National Committee on Large Dams, *Guidelines for Design of Dams for Earthquakes*, August 1998.

ANCOLD 2000a, Australian National Committee on Large Dams, *Guidelines on Selection of Acceptable Flood Capacity for Dams*, March 2000.

ANCOLD 2000b, Australian National Committee on Large Dams, *Guidelines on Assessment of the Consequences of dam Failure*, May 2000.

ANCOLD 2003, Australian National Committee on Large Dams, *Guidelines on Risk Assessment*, October 2003.

AR&R 1999, *Australian Rainfall and Runoff. – Estimation of Large to Extreme Floods Book VI in Australian Rainfall and Runoff - A Guide to Flood Estimation, The Institution of Engineers, Australia, Barton, ACT, R.J.Nathan and P.E.Weinmann.*

AS/NZS 4360 2004, "Risk Management", August

Bureau of Meteorology (BoM 2003a), *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method*, June 2003. http://www.bom.gov.au/hydro/has/gsdm_document.shtml

Bureau of Meteorology (BoM 2003b), *Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Tropical Storm Method*, November 2003.

Hargraves, Gary, 2004, *Final report, Extreme Rainfall Estimation Project " CRCFORGE and (CRC)ARF Techniques, Queensland and Border Locations, Development and Application*", Water assessment Group, Natural Resources &Mines

Graham, W. J., 1999, *A Procedure for Estimating Loss of Life Caused by Dam Failure*, US Department of Interior, Bureau of Reclamation, DSO-99-06, Denver, Colorado, September.

NR&M, 2002a, Queensland Government, Natural Resources & Mines, *The Queensland Dam Safety Management Guidelines*, February 2002. http://www.nrw.qld.gov.au/compliance/wic/guidelines_refer_dams.html

NR&M, 2002b, Queensland Government, Natural Resources & Mines, *The Guidelines for Failure Impact Assessment of Water Dams*, April 2002. http://www.nrw.qld.gov.au/compliance/wic/guidelines_refer_dams.html

NR&M, 2002c, Queensland Government, Natural Resources & Mines, *Guidance on the Assessment of Tangible Flood Damages*, September 2002. http://www.nrw.qld.gov.au/water/use/pdf/tangible_flood_damages.pdf

Queensland Treasury, 2000, *"Guidelines for Financial and Economic Evaluation of New Water Infrastructure in Queensland,* http://www.treasury.qld.gov.au/office/knowledge/docs/water-infrastructure/index.shtml

Queensland Treasury, 1997, *"Project Evaluation Guidelines"*.

USBR, 1981, US Department of the Interior, Bureau of Reclamation, *Freeboard Criteria and Guidelines for Computing Freeboard Allowances for Storage Dams*, ACER Technical Memorandum No. 2, Denver, Colorado.

USBR, 1987, US Department of the Interior, Bureau of Reclamation, *Guidelines for Using Fuse-plug Embankments in Auxiliary Spillways*, ACER Technical Memorandum No. 10, Denver, Colorado.

Appendix A - Summary of Written Acceptable Flood Capacity Assessment Requirements

Summary of Written Acceptable Flood Capacity Assessment Requirements

The Acceptable Flood Capacity Assessment must be certified by a registered professional engineer as accurate and reasonable. The following information must be included in a written Acceptable Flood Capacity Assessment report:

Executive Summary/Introduction

A general description of the dam and the result of the Acceptable Flood Capacity Assessment including:

- Name of dam;
- Location of dam (i.e. longitude and latitude);
- Real property description of the land on which the dam structure is located
- Photographs of the existing dam or dam site
- Name of the owner of dam (i.e. name of individual or company).
- Dam owner contact details (i.e. postal address, street address, phone number, facsimile, email);
- Status of dam (i.e. existing or proposed dam or proposed work);
- Date dam construction completed to current arrangement;
- Development permit and water licence details (if any);
- Date last failure impact assessment accepted by the chief executive;
- The maximum population at risk;
- The failure impact assessment category for the dam;
- Type of dam (i.e. homogenous earthfill dam, zoned earth and rockfill dam, concrete dam or other);
- Height and storage capacity of the dam;
- Dam capacity to Full Supply Level (in megalitres);
- Spillway description (Type & Dimensions);
- Spillway discharge rating curves and any applicable operational rules (for gated operations) used in determining the AFC;
- Existing Flood Discharge Capacity for the dam at the dam crest level or a level with the design freeboard;
- AEP of the Existing Flood Discharge Capacity
- Acceptable Flood Capacity (AFC) for the dam;
- Spillway Design Flood and, if it is less than the AFC, details as to how it was assessed and the impacts of floods in excess of the Spillway Design Flood;
- Identified current flood discharge capacity as a percentage of AFC.

Data and methodology used

The Acceptable Flood Capacity Assessment shall include a summary of the data on which the assessment is based and the details of the methodology used (small dams standard/ fallback option /risk assessment) including, but not limited to the following:

Risk assessment	Small Dams Standard/Fallback Option
- Description of methodology for determining design rainfalls and results; - Description of methodology for determining spillway capacity floods and the results of routing the floods through the storage; - Description of methodology for assessing consequences of failure - Basis of the risk assessment process, methodology, parameter values and uncertainties including documentation as to: - Demonstrate the appropriateness of the assessment; - How the risks were identified and assessed; - What systems are applied to ensure the risks are properly controlled?	- Description of methodology for determining design rainfalls and consequent flood magnitudes; - Details of the operating procedures adopted in determining the AFC; - Details of consequences of dam failure for Sunny Day and Flood failure conditions - PAR for each failure case considered; - Interpolations.

Details of the review of the appropriateness and accuracy of the data (including the details of dam break analyses for "Fallback Option") must be also included in the assessment.

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

Assessment

Details of the assessment including, but not limited to the following:

Existing Dams	Proposed dams
- Dam Crest Flood (DCF) for the existing arrangement, with the assigned Annual Exceedance Probability (AEP), to ANCOLD *Guidelines on Selection of Acceptable Flood Capacity for Dams,* Appendix 1. - For dams with hazard category of *Extreme* or *High A*, 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 hazard category of *High B* or *High C*, 'PMP Design flood' based on Book VI procedures with the reservoir at FSL at the start of the flood event or sequence of flood events. - The assessed hazard category, 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. - Assessment of the allowance for freeboard with reasons - Note of any changes to dam management, operating rules, conditions and surveillance procedures since the previous review report. - Information on EAPs in place. - Identified hydrologic deficiencies including assessment against Guideline criteria - Estimated risks of failure and assessment of their tolerability. - Capacity to accommodate future climate change (i.e. what is in reserve?)	- Assessed hazard category and consequences – total and incremental - are to be reported including the potential for loss of life. - Hydrologic assessment against deterministic criteria. (needs further definition) - DCF and PMF and/or PMP Design flood, as for review of existing dams, and appropriate. - Proposals for freeboard provisions with reasons for the nominated freeboard. - Proposals, including assessed risks, for flood management during construction - Proposed dam management operating rules, conditions and surveillance procedures. - Provisions, if any, for future climate change.

Risk reduction proposals for existing dams (following the completion of an assessment for the dam)

Risk reduction measures only need to be considered as part of the risk assessment process when considering whether ALARP has been satisfied.

- Risk reduction options considered and comparative assessments against existing arrangement.

- Proposed DCF, PMF and/or PMP Design Flood, with assigned AEP, as appropriate for each of the options considered.

- Assessed hazard category and potential dam failure consequences, after implementation of risk reduction measures.

- Details of any structural measures to be relied on for risk reduction including changes to spillways or dam embankments etc.

- Details of any proposed non-structural measures to be relied on for risk reduction including changes to dam management, operating rules and flood warning systems, conditions and surveillance procedures.

- Proposed freeboard provisions and basis for these for each of the options considered.

- Proposals, including assessed risks, for flood management and construction management during construction.

- Interim EAPs, both during planning and during construction.

Registered Professional Engineer details.

The Acceptable Flood Capacity Assessment is to incorporate a certification from a Registered Professional Engineer (RPEQ). This certification shall include:

- Name of the certifying RPEQ.

- Registration number.

- Contact details (including postal address, street address, telephone number, facsimile, email as appropriate).

- A statement that this AFC assessment is reasonable and accurate and has been done in accordance with the NRW Guidelines on Acceptable Flood Capacity for Dams;

- Signature of RPEQ.

- Date.

Appendix B - Methodology for Demonstrating Compliance with ALARP.

Methodology for demonstrating compliance with ALARP.

The **ALARP principle** requires that risks should be 'as low as reasonably practicable'. The methodology for demonstrating risks are ALARP is to be applied to all assessments where the "risk assessment procedure" is used for determining Acceptable Flood Capacity.

This requirement is to reduce risks to life to the point where further risk reduction is impracticable or requires action that is grossly disproportionate in time, cost, trouble and effort to the reduction in risk achieved. This principle forms the balance between equity and efficiency, with the balance deliberately skewed in favour of equity.

To decide whether risks are ALARP, it is necessary to consider the possibilities for further risk reduction beyond the limits of tolerability and their relative ease or difficulty (the sacrifice) of implementing them and to balance these against the benefits of implementing them. To demonstrate this, for the purposes of these guidelines, it is necessary to formulate risk reduction options and to prepare concepts and realistic cost estimates to undertake the risk reduction measures.

Each case will depend on the circumstances of the dam under consideration, but further risk reduction measures considered should not only include major modifications to the dam structure but should also include modifications or additions of individual pieces of equipment and/or components of individual structures where such measures are likely to have a significant impact on the overall risk of dam failure. In assessing the costs of these further risk reduction measures, only the incremental costs associated with risk reductions beyond the limit of tolerability should be considered[9].

By undertaking the activities detailed in these guidelines and incorporating the outcomes in their decision recommendations, the analysts can assist the decision-maker, who has to make the final judgement that risks are ALARP.

A particular owner's ability or inability to afford a risk reduction measure – that is, the owner's financial circumstances - is not a consideration in deciding whether life safety risks are ALARP.

The methodology outlined below presents a cost-benefit framework for determining whether the ALARP upgrade improvements are required. This methodology assumes that a number of engineering calculations have already been performed to determine the probability of a flood event or other hazard (e.g. seismic, wind, piping) causing dam failure based on the probability of the event over the life of the dam and the expected loss of life during the event. The answers to these calculations are then applied to the methodology presented below.

A range of potential ALARP spillway capacity upgrades (including any necessary structural upgrades to accommodate additional headwaters and flows) should be considered in the assessment. The levels of these upgrades must then be used to develop a cost benefit curve for the spillway upgrade options, so that the point at which costs equal benefits can be identified. This optimal ALARP upgrade standard should then be compared with and plotted on the same graph as the limit of tolerability to demonstrate the upgrade point with which dam owners are required to comply.

The methodology requires the probable loss of life due to dam failure[10] and probable property damage over the life of the dam due to dam failure to be determined, for both the project that just satisfies the tolerable risk criteria without consideration of ALARP[11] and a range of further potential ALARP spillway upgrades.

The probability of loss of life due to dam failure over the dam's life is calculated by examining the

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[9] Where the overall dam upgrade project is to proceed as one overall project, the project costs associated with an ALARP component of the project should only include that proportion of the overall establishment costs associated with the upgrade of the works beyond the 'tolerable limit'.

[10] Note that probability of expected loss of life due to dam failure over the life of the dam may also be expressed as the probability of death and dam failure occurring at the same time.

[11] The minimum tolerable spillway standard prior to the consideration of ALARP is the spillway capacity which just allows the risk profile to meet the limit of tolerability criteria.

population at risk, the fatality rate[12] and the probability of dam failure during a flood event (or the flood event plus a proportional increase in discharge capacity equal to the level of ALARP upgrade being examined) over the nominated design life of the dam[13] for the particular catchment. The probability of expected loss of property due to dam failure over the dam's life is calculated by examining the property at risk, the expected damage during a flood event and the probability of dam failure during that flood event (or the flood event plus a proportional increase in discharge capacity equal to the level of ALARP upgrade being examined).

The first calculation in the methodology should be applied to the dam arrangement that just satisfies the tolerable risk criteria without consideration of ALARP, as follows:

$$E(LOL_{dam\ life}) = [\Sigma\ (F_i \times PAR_i)] \times P(FE)$$

which simplifies to:

$$E(LOL_{dam\ life}) = E(LOL) \times P(FE)$$

Where:

$E(LOL_{dam\ life})$ = total expected LOL over the life of the dam.

$E(LOL)$ = expected total LOL during a failure event;

F_i = fatality rate for each separate community,(i), in the particular catchment (This rate should be calculated for each community as some communities may be subject to different levels of flood severity and different flood vulnerabilities);

PAR_i = total PAR in each separate community during the failure event corresponding to the fatality rate F_i in the particular catchment;

$P(FE)$ = probability of dam failure during a flood, seismic or other event over the life of the dam;

The calculation is also applied separately to the proposed ALARP upgrade standard. That is:

$$E(LOL_{dam\ life})^* = [\Sigma\ (F_i^* \times PAR_i^*)] \times P(FE)^*$$

which simplifies to:

$$E(LOL_{dam\ life})^* = E(LOL)^* \times P(FE)^*$$

Where:

$E(LOL_{dam\ life})^*$ = total expected LOL over the life of the ALARP upgraded dam.

$E(LOL)^*$ = expected total LOL during a failure event at the ALARP upgraded dam;

F_i^* = fatality rate at ALARP upgraded dam for each separate community, (i), in the particular catchment (note that this is necessary as some individual communities comprising the PAR may be subject to different levels of flood severity and different flood vulnerabilities);

PAR_i^* = total PAR in each separate community during the failure event corresponding to the fatality rate F_i^* in the particular catchment;

$P(FE)^*$ = probability of dam failure due to a nominated flood, seismic or other event greater than the minimum tolerable spillway standard over the life of the ALARP enhanced dam;

Once the expected loss of life is determined based on a dam complying with the tolerable risk level and the various levels of ALARP upgrade, the incremental reduction in the probability of loss of life from dam failure as a result of the ALARP upgrade being performed may be calculated. This requires the difference in the total expected loss of life calculated in the first step to be calculated, as follows:

$$E(LOL_{dam\ life})_{Incremental} = E(LOL_{dam\ life}) - E(LOL_{dam\ life})^*$$

Where:

$E(LOL_{dam\ life})_{Incremental}$ = incremental reduction in total expected LOL over the life of the dam due to the ALARP upgrade being performed

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[12] The 'fatality rate' is the appropriate fatality rate in Graham's loss of life formula (Graham, 1999) assuming 'no warning time' unless a strong case to the contrary is made.

[13] To be taken as 150 years from the completion of the spillway upgrade.

Similarly, the expected property damage can be considered by determining the incremental flood damage due to the failure of the dam during an event and the changes to the operations and maintenance costs due to the upgrade.

$$E(Damages_{dam\ life})_{incremental} = E(Damages_{dam\ life}) - E(Damages_{dam\ life})^*$$

Where:

$E(Damages_{dam\ life})_{incremental}$ = Incremental damages due to the dam failure event

$E(Damages_{dam\ life})$ = the expected total damages resulting from the event without dam failure

$E(Damages_{dam\ life})^*$ = the expected total damages resulting from the event with dam failure

The expected damages are to be based on the NRW *Guidance on the Assessment of Tangible Flood Damages* (NR&M 2002c).

This incremental reduction in the estimated loss of life over the life of the dam, attributable to the ALARP upgrade being performed is then used to determine the expected total benefit $(E(TB_t))$ resulting from the ALARP upgrade. This is done by multiplying the VOSL by the incremental reduction in the estimated over the life of the dam due to the ALARP upgrade being performed, as shown below.

$$E(TB_t) = E(LOL_{dam\ life})_{Incremental} \times VOSL$$

It is presumed that the expected total benefit will be achieved in the year the upgrade is completed (ie, time = t). This is the case as the reduction in the probability of dam failure as a result of an increase in the level of AEP flood event that the upgraded dam can endure, will occur in the year that the upgrade work is completed. This benefit is not accrued in prior or subsequent years, as the timing of the total benefit is taken to align with the reduction in risk and the completion of work.

A societal discount rate of 6%, as noted in Queensland Treasury Guidelines (Qld Treasury, 2000 and Qld Treasury 1997) is to be adopted when determining the net present value of cash flows. The expected total cost of the upgrade should also be ascertained in current year dollars using the same societal discount rate. This will necessarily require the dam owner to consider the timing of cash flows associated with the upgrade and apply a similar 6% discount rate. The discounting calculations are presented below.

$$E(TB_0) = E(B_t) / (1+r)^t$$

and

$$E(TC_0) = [E(C_t) / (1+r)^t] + [E(C_{t-1}) / (1+r)^{t-1}] + [E(C_{t-2}) / (1+r)^{t-2}] + ... + [E(C_{t-n}) / (1+r)^{t-n}]$$

Where:

r = societal discount rate
t = the time period in which the benefit will be received and the costs will be incurred
$E(TB_0)$ = expected total benefit in current year dollars
$E(TC_0)$ = expected total cost in current year dollars

These expected total benefits and costs may then be compared to establish if the ALARP upgrade is likely to produce total benefits in excess of total costs (ie, a cost benefit ratio of less than unity). If the net benefit is positive then the project should go ahead. The cost-benefit decision calculation is presented below:

If: $E(TC_0) / E(TB_0) \leq 1$ → ALARP spillway upgrade required
          $E(TC_0) / E(TB_0) > 1$ → ALARP spillway upgrade not required

This calculation illustrates that where the analysis produces a cost to benefit ratio of less than or equal to one (ie, benefits at least match the costs), then the ALARP upgrade would be required. An example of how this methodology should be applied appears in the example presented below.

Through this process, the cost benefit curve can be plotted so that the appropriate level of dam upgrade may be identified.

From a social economic perspective, the appropriate level of upgrade beyond the limit of tolerability would be where the marginal benefits of the total spillway upgrade equal the marginal costs of the total spillway upgrade. This is the point at which total net benefits are maximised. This point may be determined by graphing the cost benefit curve, of total expected benefits against the relative increase in flood discharge capacity based on the calculations performed for the range of ALARP spillway upgrades.

When relying on 'risk assessment', dam owners are required to undertake upgrades at least to the 'tolerable risk' line. The extent to which the spillway needs to be further upgraded depends on whether the point at which the total benefits equal the total costs lies beyond the limit of tolerability or not.

ALARP upgrade options to be considered

There are a wide range of potential upgrade options to be considered as part of the upgrade process to reduce the risks below the tolerable risk level. Such options that might be considered include (but may not be limited to):

- Widening or deepening an existing spillway

- The addition of spillway gates or some other flow control structure

- Modifying the operating systems/rules for the structure so that risk of failure is reduced

- Structural modifications to the dam to enable it to safely pass overtopping flows

- Additions/modifications to dam embankments and foundations to reduce the risk of failure

- The addition of additional spillways such as higher level auxiliary spillways or fuse plug spillways

- Raising or modifying non-overflow dam sections to reduce the risk of failure

- Diversion of some of the catchment around the dam

- A combination of any or all of the above.

The required accuracy of the necessary estimates for these options will be dependent on the sensitivity of the outcome. The accuracy need not be high where the result is clear-cut one way or the other.

The actual ALARP upgrade options to be considered in each particular case will be dependent on the circumstances at each individual dam and advice may need to be sought from an RPEQ experienced in dam engineering. Non-structural options can only be considered if it can be clearly demonstrated that such options can be relied on in the long term and are under some degree of control by the dam owner.

Example

An example of the ALARP methodology is provided below to illustrate the practical application of calculating the life benefits achieved by upgrading the size/capacity of a spillway by 10% beyond the limit of tolerability standard. The assumptions made below are presumed to have been provided through engineering studies and calculations

Figure B1 - Example of Demonstrating Compliance with ALARP
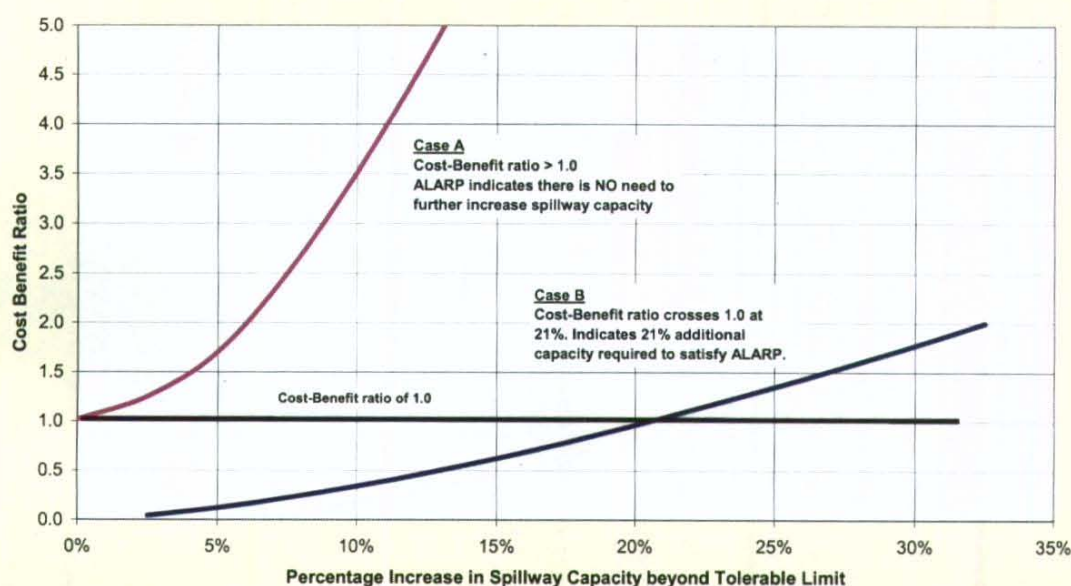
Assumptions:

$P(FE)$ = 0.04878 (= probability of a 1 in 3000 year AEP event occurring over a 150 year life of the dam)

$P(FE)^*$ = 0.02107 (= probability of a 1 in 7045 year AEP event [equivalent to a 10% increase in spillway capacity] occurring over a 150 year life of a dam

F = 0.15 (for medium severity flooding where houses would be damaged during flood events)

PAR = 10 (obtained from Failure Impact Assessment studies)

$VOSL$ = \$5m AUD (2004 dollars)[14]

r = 6%

t = 5 (ie, upgrade will be completed in year 5)

$E(TC)$ = \$250,000   (ie, expected total cost of ALARP upgrade over five years as follows: year 1: 5%; year 2: 5%; year 3: 15%; year 4: 35%; year 5: 40%)

Probability of death given dam failure

Under tolerable safety standard
$$E(LOL_{dam\,life}) = [(F_i \times PAR_i) + (F_k \times PAR_k) + (F_m \times PAR_m)] \times P(FE)$$
$$= [0.15 \times 10] \times 0.04878 = 0.07317$$

After ALARP spillway improvement
$$E(LOL_{dam\,life})^* = [(F_i^* \times PAR_i) + (F_k^* \times PAR_k) + (F_m^* \times PAR_m)] \times P(FE)^*$$
$$= [0.15 \times 10] \times 0.02107 = 0.03160$$

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[14] Assumed based on a figure within the strong to very strong ANCOLD justification range for risks just above the broadly acceptable risk.

Incremental reduction in probability of death given dam failure

$$\textit{Incremental } E(LOL_{\textit{dam life}}) = E(LOL_{\textit{dam life}}) - E(LOL_{\textit{dam life}})^*$$
$$= 0.07317 - 0.03160 = 0.04157$$

Expected Benefit of ALARP spillway upgrade

In year 5:

$$E(B_t) = \textit{Incremental } E(LOL_{\textit{dam life}}) \times VOSL$$
$$E(B_5) = 0.04157 \times \$5,000,000 = \$207,850$$

At time zero:

$$E(B_0) = E(B_t) / (1+r)^t = \$207,850 / 1.06^5 = \$155,990$$

Expected indexed Cost of ALARP spillway upgrade at time zero

$$E(C_0) = [E(C_t) / (1+r)^t] + [E(C_{t-1}) / (1+r)^{t-1}] + [E(C_{t-2}) / (1+r)^{t-2}] + ... + [E(C_{t-n}) / (1+r)^{t-n}]$$
$$= \$100,000 / 1.06^5 + \$87,500/1.06^4 + \$37,500/1.06^3 + \$12,500/1.06^2 + \$12,500/1.06$$
$$= \$198,500$$

Cost-Benefit Analysis

$$E(C_0) / E(B_0) = \$198,500 / \$155,900 = 1.27$$

In this example, for this potential project, as the costs of undertaking the additional upgrade outweigh the benefits, the dam owner would not be required to increase the minimum safety of the spillway by 10% above the tolerable limit to sustain a larger AEP flood event. Had the benefits outweighed the costs however, the upgrade would have been required.

Such cost -benefit assessments should be undertaken for a range of upgrades beyond the limit of tolerability, so that the optimal level of ALARP upgrade could be identified. If this was done and a cost-benefit curve of the type shown in the Figure B1 for 'Project Type A' might result.

To achieve compliance with the minimum safety standard, dam owners are required to undertake upgrades until the optimal upgrade point is reached (being the point at which benefits equal costs). Thus, for the Project Type A example, where no point is below a Cost-Benefit ratio of 1.0, no further upgrade would be required to satisfy ALARP. However, if a cost-benefit curve like 'Project Type B' resulted, a additional 21% upgrade would be required in order to satisfy ALARP.

Appendix C - Methodology for Interpolating Required AEP within a particular Hazard Category using Fallback Procedure

Methodology for Interpolating Required AEP within a particular Hazard Category using Fallback Procedure

The following methodology can be applied for interpolating the required AEP of the Acceptable Flood Capacity within a specific Hazard Category for the Fallback procedure.

The following interpolation procedure is to be applied within any 'Severity of Damage and Loss' and 'Population at Risk' cell of Table 2:

(a) Once the consequences of failure (level of damage) and the PAR have been assessed using the provisions of Section 3.3, determine the appropriate Hazard Category and determine the Annual Exceedence Probabilities (AEPs) to be applied at each of the points A, B, C and D using the AEPs set out in Table 2. (Note the points A, B, C and D are not to be confused with the hazard category in Table 2)
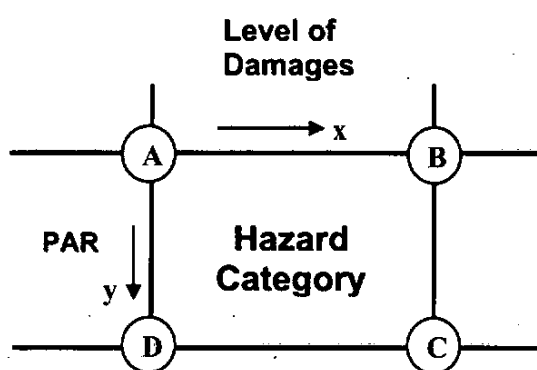
(b) Determine the 'x' and 'y' coordinates for the most critical failure case.
x = the relative severity of damage and loss relative to the boundaries of the damage scale
y = the log of the PAR

Where 'x' and 'y' are calculated as follows:

x = [$\log_{10}$(Damage)-$\log_{10}$ (Damage @ A)]/[$\log_{10}$ (Damage @ B)-Log_{10} (Damaged @ A)]

y = $\log_{10}$(PAR/10)

Where the values of damages at A/D and B/C have been interpolated from the ranges of damages contained in ANCOLD 2000b for:

1. Estimated Costs

2. Service and Business relating to the Dam

3. Social

4. Natural Environment

With the lowest AEP selected corresponding to the worst combination of 'x' and 'y' values being adopted.

Note for 'Major' levels of damage, the maximum value of the 'x' coordinate shall be taken to correspond to twice the level of damages at the boundary between 'medium' and 'major'.

(c) Using the following relationship, determine for each combination of 'PAR' and 'Level of Damages' the required AEP of the design flood and select the smallest AEP as the required AEP of the AFC.

Log(AEP) = $\alpha_1 + \alpha_2 x + \alpha_3 y + \alpha_4 xy$

Where

α_1 = the log (AEP) of the design flood at point A
α_2 = the log (AEP) of design flood at point B - α_1
α_3 = the log (AEP) of design flood at point D - α_1
α_4 = the log (AEP) of design flood at point C - α_1 - α_2 - α_3

By way of example for the case of

- a PAR of 29 and serious damage or destruction of 10 houses producing a 'Medium' level of residential damages[15].

- A catchment area of less than 100km^2

Because the catchment area is less than 100 km^2, Table 2 indicates the notional AEP of the Probable Maximum Precipitation is 1.0x10-7 and the Hazard Category is 'High C'.
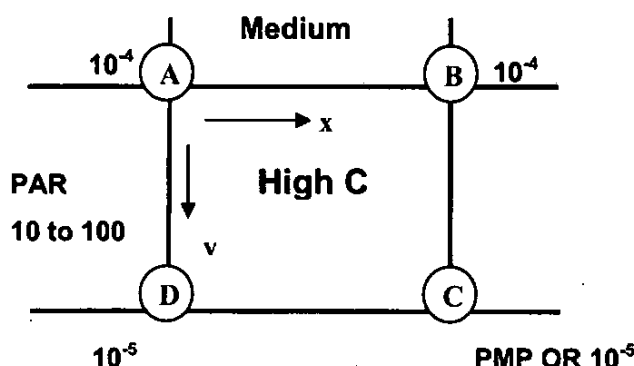
Point 'A' corresponds to a PAR of 10 and, from Appendix D of ANCOLD *Guidelines on Assessment of Consequences of Dam Failure* (ANCOLD, 2000b), a level of damages equivalent to the destruction of four houses.

Point 'B' corresponds to a PAR of 10 and a level of damages equivalent to the destruction of forty-nine houses.

Point 'C' corresponds to a PAR of 100 and a level of damages equivalent to the destruction of forty-nine houses.

Point 'D' corresponds to a PAR of 100 and a level of damages equivalent to the destruction of four houses.

From Table 2 of this Guideline, the AEP of the AFC at point 'A' and 'B' is 1.0x10-4 and the AEP of the AFC at points 'C' and 'D' is the probability of the PMP or 1.0x10-5 (whichever is greater) i.e 1.0x10-5.

Thus ...

At point A $y = \log(10) = 1$, $x = 0$, required AEP = 1.0×10^{-4}
At point B $y = \log(10) = 1$, $x = 1$, required AEP = 1.0×10^{-4}
At point C $y = \log(100) = 2$, $x = 1$, required AEP = 1.0×10^{-5}
At point D $y = \log(100) = 2$, $x = 0$, required AEP = 1.0×10^{-5}

At the point of interest $x = (\log 10 - \log 4)/(\log 49 - \log 4) = 0.366$

$$y = \log_{10}(29/10) = 0.4624$$

$$\alpha_1 = \log_{10}(1.0 \times 10^{-4}) = -4$$

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[15] Under the ANCOLD Guidelines on the Assessment of Consequences of Dam failure (ANCOLD 2000b) a 'Medium' level of residential damages corresponds to 'Destroy 4 to 49 houses or damage to a number'.

$$\alpha_2 = \log_{10}(1.0 \times 10^{-4}) - \alpha_1 = -4 - (-4) = 0$$

$$\alpha_3 = \log_{10}(1.0 \times 10^{-4}) - \alpha_1 = -5 - (-4) = -1$$

$$\alpha_4 = \log_{10}(1.0 \times 10^{-5}) - \alpha_1 - \alpha_2 - \alpha_3 = -5 - (-4) - (-1) - 0 = 0$$

Which gives a required AEP of the Acceptable Flood Capacity of

$$\text{Log(AEP)} = \alpha_1 + \alpha_2 \, x + \alpha_3 \, y + \alpha_4 \, xy$$

$$= -4 + 0 * x - 1 \, y + 0 * x \, y$$

$$= -4 - 1 * 0.4624 = -4.4624$$

Therefore the required AEP is $1 \times 10^{-4.4624} = 3.45 \times 10^{-5}$