Guidelines on Acceptable Flood Capacity for Water Dams

July 2017
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.

Section 572 of the Water Supply (Safety and Reliability) Act 2008 (the Act) empowers the chief executive of the Department of Energy and Water Supply (DEWS) to make guidelines for:

- applying safety conditions to referable dams
- flood capacity of dams.

This document is a guideline issued by a duly authorised delegate of the chief executive pursuant to sections 354(2) and 572 of the Act. 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 standard and implementation policy (as contained in this guideline) against which all referable dams in Queensland will be assessed and to alert 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 ability of water dams to be able to safely discharge an acceptable flood capacity. These guidelines specify the minimum required acceptable flood capacity (AFC) all proposed and existing referable dams in Queensland must be able to safely pass. For dams which are not referable, the guidelines are advisory.

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 DEWS
- 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 the ‘as low as reasonably practicable’ principle (ALARP).

1 Under the Water Supply (Safety and Reliability) Act 2008, referable dams are those assessed, using the DEWS Guidelines for Failure Impact Assessment of Water Dams (DERM, 2010), as having a population at risk of two or more in the event of any potential failure of the dam.
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.

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 the Australian National Committee on Large Dams 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 realise that many of the rainfall estimates from years past are well below current estimates. In many cases the flood for which the dam should be designed 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 owner’s 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 DEWS. 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 Supply (Safety and Reliability) Act 2008

The Act provides the regulatory framework for dam safety of water dams in Queensland. Under section 353 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 section 356 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 and the Guidelines for Failure Impact Assessment of Water Dams have been issued by DEWS 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 DEWS 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) acceptable flood capacity without failure of the dam

(b) 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 the:

(a) magnitude of the adopted spillway design flood, how it was determined and why it is considered acceptable

(b) 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) 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) 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 are based on a range of ANCOLD and other guidelines as listed below:

- Selection of Acceptable Flood Capacity for Dams (ANCOLD, 2000)
- Assessment of the Consequences of Dam Failure (ANCOLD, 2000)

---

2 Under the Water Supply (Safety and Reliability) Act 2008, 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 the dam’s contents.
• Risk Assessment (ANCOLD, 2003)

As most of the processes from the relevant ANCOLD and ARR 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 DEWS guidelines, 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.

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 DEWS. 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 of 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 annual exceedance probability (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, Bureau of Reclamation, Guidelines for Using Fuse Plug Embankments in Auxiliary Spillways (USBR, 1987):

(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

(m) assured access to all necessary locations on the dam for necessary operations during a flood event

(n) 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 in sections 3.2 to 3.4 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 and
- a PAR of 15 or less and
- uncontrolled spillways and
- 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

---

3 Until a Queensland guideline is developed on earthquake loadings for referable dams, the ANCOLD Guidelines on 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.
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 DEWS Guidelines for Failure Impact Assessment of Water Dams (DERM, 2010) 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 acceptable flood capacity (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:

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

**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 section 3.5.

4. Route this flood through the dam.

Note: 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 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, 2000)
- ANCOLD Guidelines on Assessment of the Consequences of Dam Failure (ANCOLD, 2000)
- DEWS Guidelines for Failure Impact Assessment of Water Dams (DERM, 2010).

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, 2000) and the following qualifications:
   - the dam is to be assumed to be initially at full supply level at the start of the flood event
   - reach dimensions, timing and PAR are to be determined in accordance with the DEWS Guidelines for Failure Impact Assessment of Water Dams (DERM, 2010).

2. Determine the hazard category rating for the dam for each case in accordance with Table 1:

<table>
<thead>
<tr>
<th>Incremental population at risk (PAR)</th>
<th>Severity of damage and loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Negligible</td>
</tr>
<tr>
<td>2 ≤ PAR ≤ 10</td>
<td>Low</td>
</tr>
<tr>
<td>10 &lt; PAR ≤ 100</td>
<td>Significant Notes 2 and 5</td>
</tr>
<tr>
<td>100 &lt; PAR ≤ 1000</td>
<td>Note 1</td>
</tr>
<tr>
<td>PAR &gt; 1000</td>
<td>Note 3</td>
</tr>
</tbody>
</table>

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

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 ANCOLD Guidelines on Assessment of the Consequences of Dam Failure (ANCOLD, 2000) for an explanation of the range of high hazard categories.

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

Guidelines on Acceptable Flood Capacity for Water Dams, Department of Energy and Water Supply, 2017 8
Table 2: Required range of acceptable flood capacities for different hazard categories

<table>
<thead>
<tr>
<th>Incremental population at risk (PAR)</th>
<th>Severity of damage and loss</th>
<th>Negligible</th>
<th>Minor</th>
<th>Medium</th>
<th>Major</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 ≤ PAR ≤ 10</td>
<td>Low</td>
<td>5.0x10^-4</td>
<td>5.0x10^-4</td>
<td>1.0x10^-4</td>
<td>1.0x10^-5</td>
</tr>
<tr>
<td></td>
<td>Significant</td>
<td>5.0x10^-4</td>
<td>1.0x10^-4</td>
<td>1.0x10^-4</td>
<td>1.0x10^-5</td>
</tr>
<tr>
<td>10 &lt; PAR ≤ 100</td>
<td>Low</td>
<td>5.0x10^-4</td>
<td>1.0x10^-4</td>
<td>1.0x10^-4</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Significant</td>
<td>5.0x10^-4</td>
<td>1.0x10^-4</td>
<td>1.0x10^-4</td>
<td>1.0x10^-5</td>
</tr>
<tr>
<td>100 &lt; PAR ≤ 1000</td>
<td>Low</td>
<td>5.0x10^-4</td>
<td>1.0x10^-4</td>
<td>1.0x10^-4</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Significant</td>
<td>1.0x10^-4</td>
<td>1.0x10^-4</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1.0x10^-4</td>
<td>1.0x10^-4</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1.0x10^-4</td>
<td>1.0x10^-4</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1.0x10^-4</td>
<td>1.0x10^-4</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1.0x10^-4</td>
<td>1.0x10^-4</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>PAR &gt; 1000</td>
<td>If in this region, go to the next highest severity of damage and loss category for the same PAR</td>
<td>PMF</td>
<td>PMF</td>
<td>PMF</td>
<td>PMF</td>
</tr>
</tbody>
</table>

Where

A = PMP design flood
B = PMP design flood or 10^-4, 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 probable maximum precipitation (PMP) design flood is a function of the catchment area.
4. Interpolate (using the procedure defined in Appendix C) within the nominated range to determine the required 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 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, 2000)
- ANCOLD Guidelines on Assessment of the Consequences of Dam Failure (ANCOLD, 2000)
- DEWS Guidelines for Failure Impact Assessment of Water Dams (DERM, 2010) (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 exceedance 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 ANCOLD Guidelines on Selection of Acceptable Flood Capacity for Dams (ANCOLD, 2000). 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 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.
• breach dimensions and timing are determined in accordance with the DEWS Guidelines for Failure Impact Assessment of Water Dams (DERM, 2010).

Total PAR is estimated using the procedures contained in the DEWS Guidelines for Failure Impact Assessment of Water Dams (DERM, 2010) or ANCOLD Guidelines on Assessment of the Consequences of Dam Failure (ANCOLD, 2000):

• 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 LOL during a dam break event is based on the total population at risk rather than the incremental population at risk produced by the DEWS Guidelines for Failure Impact Assessment of Water Dams (DERM, 2010). 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:

\[
\text{Incremental LOL due to failure event} = (\text{LOL for flood event with dam failure}) \text{ less to due failure event} (\text{LOL for same event without dam failure})
\]

• 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 (ANCOLD, 2003)] 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 (ANCOLD, 2003)], is unacceptable, except in exceptional circumstances.

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, for example 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 $6.2 million (in 2012 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 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.

---

\(^7\) 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 AEP for all 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 DERM 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)
- appropriate methodology for assessing probable maximum precipitation (PMP), in accordance with:
  - the Bureau of Meteorology (BoM) the Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method (GSDM, BoM, 2003), or
- provisions of AR&R 1999 shall be used for interpolating rainfall magnitudes between the CRC Forge rainfalls and the PMPs.

(b) The run-off 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 & Run-off—Volume 1 (ARR 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**

![Varying duration storm events having the same AEP](image)

(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 (for example, as in some mass concrete dams), the analysis can take this discharge into account. However, if they are not designed to accommodate discharge (for example, 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) 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) 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.


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
- potential for future developments downstream requiring additional flood discharge capacity
• 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
• 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 flood discharge 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 as outlined in these guidelines. 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 are required to be designed and constructed to deliver the acceptable flood capacity as determined in accordance with this guideline from when they become operational or start to permanently store water.

Owners of all existing referable dams, which cannot safely discharge the acceptable flood capacity, will be required to upgrade their dams such that this discharge capacity is provided at their dams.

In previous versions of the guideline, a single upgrade schedule applied regardless of the method used to assess the adequacy of the current spillway. Separate upgrade schedules or requirements are now introduced for where the standards based methods (small dams or fall-back) and risk based methods (risk assessment) are applied.

As discussed in section 1 of this guideline, dam owners need to be aware that the adoption of a standards based methodology to determine the acceptable flood capacity for the dam will not address all of the potential failure modes for the dam.

The application of risk assessment methodologies has matured in recent times with more consistent results now being achieved. These methodologies are now being much more widely used, particularly by owners of multiple large dams as they take a more complete ‘all hazards’ approach to the assessment of dam failure risks.
The programming of any necessary dam safety upgrade works is to take into account, factors such as the time necessary to complete the work before the due date and the time of year available to undertake the work so as to minimise any additional risk to those living downstream. Any variations potentially extending this program beyond the due date—either specified or as otherwise agreed with the chief executive of DEWS for risk-assessed cases—should be discussed with the chief executive of DEWS.

Owners of existing dams may choose to stage spillway upgrades to meet these timeframes or to undertake all required works to meet the required standard in one stage. However, it is also strongly recommended that, in order to minimise the risk of requiring further upgrades in quick succession:

(a) The required discharge capacity be reassessed before undertaking of final spillway upgrade works to ensure that the required acceptable flood capacity has not changed and that the required spillway capacity is still consistent with the specified upgrade program and emerging issues are appropriately considered.

(b) Likely future downstream developments may be taken into account when assessing the required spillway capacity.

All dams that are being significantly modified to increase their full supply level storage volume will also be required to provide a total discharge capacity equal to the acceptable flood capacity as part of the modification process.

Care will be needed during all dam upgrades to ensure that any increases in risk during the upgrade process are assessed and risk mitigation measures are documented and implemented to manage these risks. Risks should not be aggravated during the construction process.

4.1 Schedule for existing dams assessed using small dams standard or fall back option

The timing of any necessary upgrade works for dams whose spillway adequacy was assessed using the small dams standard or the fall back option 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

- $Q_{\text{trial}}$ = The inflow hydrograph ordinate of the trial flood event
- $Q_{\text{cdse}}$ = 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 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\(^8\).

This proportion of the acceptable flood capacity is taken to be the discharge capacity of the
existing dam.

**Table 3: Schedule for dam safety upgrades**

<table>
<thead>
<tr>
<th>Tranche</th>
<th>Required minimum flood discharge capacity</th>
<th>Date by which the required minimum flood capacity is to be in place for existing dams</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25 per cent of AFC or with at least 1:2,000 AEP for erodible dam embankments (whichever is the bigger flood)</td>
<td>1 October 2015</td>
</tr>
<tr>
<td>2</td>
<td>65 per cent of AFC</td>
<td>1 October 2025</td>
</tr>
<tr>
<td>3</td>
<td>100 per cent of AFC</td>
<td>1 October 2035</td>
</tr>
</tbody>
</table>

### 4.2 Schedule for existing dams assessed using risk assessment procedures

The general aim of all dam upgrades based on risk assessment approaches is to ensure all required
dam safety upgrades are completed by not later than 1 October 2035 (this date aligns with the
upgrade completion timing outlined in section 4.1).

Given the amount of interpretation and assumptions required for risk assessment, a definitive
schedule, such as that contained in Table 3, will not be provided.

Instead, dam owners should apply the following general principles:

(a) Where the dam owner owns a significant number of dams requiring upgrades (i.e. 5 or more)
the general aim should be to progressively complete the upgrades over the period until 1
October 2035. To provide further guidance:

- Dams with risk greater than the limits of tolerability are to be prioritised first, ranked in
descending order of life safety risk.
- If a dam failure risk is being addressed (in this manner) to achieve upgrade as per this
guideline, the risk will be considered to be an acceptable risk.
- Note that emergent risks, such as those arising from scouring during a flood event, may
significantly change the risk profile of a dam and change the priority and scope of
associated upgrades. All emerging risks that are to be addressed in an upgrade program
should be prioritised and scheduled within the overall upgrade program.

---

\(^8\) 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 Exceedance Probability of the overall event is to be the combined probability of the flood
causating 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
• Dams being upgraded in order solely to satisfy ALARP considerations should be prioritised after those that don’t already satisfy the limits of tolerability.
• The risk reduction projects should be scheduled over the period to 1 October 2035 such that the program is commensurate with the capacity of the organisation. Upgrade costs should be spread over that period (unless risk considerations require an alternative).

(b) For all other dam owners, the upgrade schedule should be determined in consultation with the dam safety regulator. The level of life safety risk relative to the ‘limit of tolerability’ will be an important consideration in the required schedule.

4.3 Situations requiring consideration of reducing the full supply level of dam for safety reasons

This section describes situations that may be represent an ‘unacceptable risk’ of dam failure for the purpose of section 399B of the Water Supply (Safety and Reliability) Act 2008 and is strictly only for that purpose.

This guideline provides two approaches—standards based and risk assessment for determining upgrade schedules for completion of necessary works by 2035 in order to reduce long-term risks (such as spillway inadequacy) within ‘tolerable limits’. Long-term risks above the tolerable risk limits are considered acceptable if they satisfy these schedules.

Shorter term risks arising from emergent circumstances such as embankment instabilities or concentrated leaks where dam failure could be initiated within a short period of time are not considered to be acceptable long-term risks and need to be investigated and addressed within much shorter timeframes. These shorter term risks are outside the limits of acceptable risk and must be addressed as emergency works separate to scheduled upgrades to improve the flood capacity of a dam. It is not intended that these risks would trigger a change to upgrade schedules to achieve acceptable flood capacity or bring forward scheduled works.

Under section 399B of the Act, a referable dam owner may reduce the full supply level of a dam if the owner believes, based on the advice of a registered professional engineer of Queensland (RPEQ), that there is an ‘unacceptable risk’ of a failure of a dam if it operates at the full supply level for the dam stated in the resource operations licence for the dam.

In these situations, reducing the full supply level should be considered as an immediate action to reduce the risk of a dam failure. Under section 399B, the dam owner may reduce the full supply level of a dam to a level that lowers the risk to a level acceptable to the owner, having regard to the advice of the RPEQ.

The RPEQ forming the opinion and preparing the report that there is an ‘unacceptable risk’ for section 399B should consider the situations outlined below and must undertake an inspection of the dam and review all relevant information in forming that opinion.

Possible events that could initiate dam failure:
• Spillway scour damage that is likely to continue or be exacerbated in future floods and would likely fail the dam embankment or spillway.

Possible failure in progress (confirmed or suspected):
• Identified seepage that indicates internal erosion is occurring and without intervention could lead to piping failure.

Vulnerability of the dam:
A potential seepage pathway is identified that is likely to lead to initiation of internal erosion and piping failure.

A stability assessment indicates that the dam or spillway is unstable.

A deficiency that does not meet good dam safety engineering practice such that dam failure is a significant probability under a normal load on the dam.

Damage to the dam:

- Earthquake damage has occurred that is highly likely to lead to piping failure of an embankment.
- Slope failure or other damage to the embankment has occurred that would lead to embankment failure.
- Damage to a spillway gate that would retain water when the dam is at the normal full supply level.

Any situation that is not listed above does not mean that the risk is ‘acceptable’ for other purposes (such as to identify the need, scope, and timeframe for upgrade) and simply means that the risk may not be significant enough to warrant the consideration of reducing the full supply level under section 399B or that reducing the full supply level is not an effective method of lowering risk.

### 4.4 Giving notice of reduced full supply level

If a dam owner takes action under section 399B of the Act to reduce the full supply level of a dam, as soon as practicable after reducing the full supply level, the owner must give notice of the reduced level to the chief executive of the DEWS and if the Water Act 2000, section 813, is not administered by DEWS, also give notice to the department that administers that section. The notice must:

(a) include the reasons why it is necessary to operate the dam at the reduced full supply level; and

(b) include the period for which it is necessary to operate the dam at the reduced full supply level; and

(c) be accompanied by a copy of the registered professional engineer’s advice about the reduced full supply level.

### 4.5 Reporting requirements while full supply level reduced

If the dam continues to operate at a reduced full supply level under section 399B for more than one year, pursuant to section 399C of the Act, the owner must, within one month after the end of each 12-month period after the full supply level is reduced, give a report to the chief executive of DEWS and if the Water Act 2000, section 813, is not administered by DEWS, also give a report to the department that administers that section, stating:

(a) when the owner intends to allow the dam to return to the full supply level stated in the resource operations licence for the dam; and

(b) if the owner is a service provider:

(i) the impacts the reduced full supply level has had on the provider’s customers since its reduction; and

(ii) the likely future impacts on customers for the period for which the provider proposes to keep the dam at a reduced full supply level; and

(iii) the impacts the reduced full supply level has had or is likely to have on achieving the Water Plan outcomes for a Water Plan under the Water Act 2000.
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.

Acceptable risk—for the purposes of determining dam upgrade programs based on the use of risk assessments, a risk will be considered an acceptable risk if they are to be addressed in an upgrade for the dam that is scheduled to occur in accordance with the provisions of this guideline.

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


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—design flood event having a duration which causes the maximum discharge from a dam for a given annual exceedance probability.

DCF—dam crest flood—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, for:

- embankment dams—lowest point of the embankment crest
- concrete dams—level of the non-overflow section of the dam, excluding handrails and parapets if they do not store water against them
- concrete faced rockfill dams—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—flood event occurring as a consequence of dam failure.

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

Design life—useful life for which a structure is designed.

DEWS—Department of Energy and Water Supply (previously known as the Department of Environment and Resource Management or DERM; or Department of Natural Resources and Water or NRW; or Department of Natural Resources and Mines or NRM; or Department of Natural Resources, Mines and Water or NRMW).

EAP—Emergency action plan (prepared and implemented in accordance with requirements of DEWS Queensland Dam Safety Management Guidelines (DERM, 2010).
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—assessment methodology described in section 3.3 of these guidelines.

Fatality rate—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 Supply (Safety and Reliability) Act 2008 and DEWS Guidelines for Failure Impact Assessment of Water Dams (DERM, 2010).

Flood discharge capacity—capacity to discharge floods (in m3/sec).

Freeboard—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—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—method for estimating the loss of life due to dam failure (refer to section 3.4).

Height (of dam)—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—graphical representation of a time-discharge curve of the unsteady flow of water.

Hazard category—potential incremental losses and damages directly attributable to the failure of the dam.

Incremental PAR—refer to PAR.

Limits of tolerability—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.

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

PAR—population at risk—number of persons, calculated under the guidelines referred to in section 342(1)(b) of the Water Supply (Safety and Reliability) Act 2008, 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, that is, 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.

PM design flood—flood resulting from the PMP using AEP neutral assumptions of catchment conditions.
**PMF**—probable maximum flood—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**—probability that the risk (event) will occur.

**Referable dam**—a dam, or a proposed dam for which:

(a) a failure impact assessment of the dam, or the proposed dam, is required to be carried out [under the *Water Supply (Safety and Reliability) Act 2008*]; 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 349 [of the *Water Supply (Safety and Reliability) Act 2008*], accepted the assessment.

The following are not referable dams:

(a) a hazardous waste dam

(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**—assessment methodology described in section 3.4 of these guidelines.

**Risk profile**—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**—assessment methodology described in section 3.2 of these guidelines.

**Societal discount rate**—discount rate used in determining the net present value (refer to Appendix B).

**Societal risk**—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**—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—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—dam failure which is not significantly affected by a natural flood occurring at the same time.

VOSL—value of statistical life.

Weir—barrier constructed across a watercourse below the banks of the watercourse that hinders or obstructs the flow of water in the watercourse.
6 References


Appendix A—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 (that is, 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 (that is, name of individual or company)
- dam owner contact details (that is, postal address, street address, phone number, facsimile, email)
- status of dam (that is, 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 (that is, 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 and dimensions)
- spillway discharge rating curves and any applicable operational rules—for gated operations—used in determining the acceptable flood capacity (AFC)
- existing flood discharge capacity for the dam at the dam crest level or a level with the design freeboard
- annual exceedance probability (AEP) of the existing flood discharge 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:

<table>
<thead>
<tr>
<th>Risk assessment</th>
<th>Small dams standard/fallback option</th>
</tr>
</thead>
<tbody>
<tr>
<td>• description of methodology for determining design rainfalls and results</td>
<td>• description of methodology for determining design rainfalls and</td>
</tr>
<tr>
<td>• description of methodology for determining spillway capacity floods and the</td>
<td>consequent flood magnitudes</td>
</tr>
<tr>
<td>results of routing the floods through the storage</td>
<td>• details of the operating procedures adopted in determining the AFC</td>
</tr>
<tr>
<td>• description of methodology for assessing consequences of failure</td>
<td>• details of consequences of dam failure for sunny day and flood failure</td>
</tr>
<tr>
<td>• basis of the risk assessment process, methodology, parameter values and</td>
<td>conditions</td>
</tr>
<tr>
<td>uncertainties including documentation as to:</td>
<td>• PAR for each failure case considered</td>
</tr>
<tr>
<td>o demonstrate the appropriateness of the assessment</td>
<td>• interpolations</td>
</tr>
<tr>
<td>o how the risks were identified and assessed</td>
<td></td>
</tr>
<tr>
<td>o what systems are applied to ensure the risks are properly controlled</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Existing dams</th>
<th>Proposed dams</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Dam crest flood (DCF) for the existing arrangement, with the assigned annual</td>
<td>• Assessed hazard category and consequences—total and incremental—are to</td>
</tr>
<tr>
<td>exceedance probability (AEP), to ANCOLD Guidelines on Selection of Acceptable</td>
<td>be reported including the potential for loss of life.</td>
</tr>
<tr>
<td>Flood Capacity for Dams, Appendix 1.</td>
<td>• Hydrologic assessment against deterministic criteria (needs further</td>
</tr>
<tr>
<td>• For dams with hazard category of Extreme or High A, PMF, based on Book VI,</td>
<td>definition).</td>
</tr>
<tr>
<td>ARR (Nathan &amp; Weinmann, 1999) procedures, with FSL the pre-flood reservoir</td>
<td>• DCF and PMF and/or PMP Design flood, as for review of existing dams, and</td>
</tr>
<tr>
<td>condition, and including information on the assigned values for all</td>
<td>appropriate.</td>
</tr>
<tr>
<td>influencing parameters such as temporal and spatial patterns and losses.</td>
<td>• Proposals for freeboard provisions with reasons for the nominated freeboard.</td>
</tr>
<tr>
<td>• For dams with hazard category of High B or High C, PMP Design flood based</td>
<td>• Proposals, including assessed risks, for flood management during</td>
</tr>
<tr>
<td>on Book VI</td>
<td>construction.</td>
</tr>
</tbody>
</table>
### Existing dams

- 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 (that is, what is in reserve?).

### Proposed dams

- 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 DERM Guidelines on Acceptable Flood Capacity for Dams
• signature of RPEQ
• date.
Appendix B—Methodology for demonstrating compliance with the as low as reasonably practicable principle

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 (AFC).

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.

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 (for example, 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.

---

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’.  

Guidelines on Acceptable Flood Capacity for Water Dams, Department of Energy and Water Supply, 2017  31
The methodology requires the probable loss of life due to dam failure 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 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 population at risk, the fatality rate 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 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:

\[
E(\text{LOL dam life}) = \sum (F_i \times PAR_i) \times P(FE)
\]

which simplifies to:

\[
E(\text{LOL dam life}) = E(\text{LOL}) \times P(FE)
\]

where:

- \(E(\text{LOL dam life})\) = total expected loss of life over the life of the dam
- \(E(\text{LOL})\) = expected total loss of life 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:

\[
E(\text{LOL dam life})^* = \sum (F_i^* \times PAR_i^*) \times P(FE)^*
\]

which simplifies to:

\[
E(\text{LOL dam life})^* = E(\text{LOL})^* \times P(FE)^*
\]

where:

- \(E(\text{LOL dam life})^*\) = total expected loss of life over the life of the ALARP upgraded dam
- \(E(\text{LOL})^*\) = expected total loss of life 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)

$PAR^* =$ 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:

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

where:

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

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.

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

where:

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

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

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

The expected damages are to be based on the DEWS Guidance on the Assessment of Tangible Flood Damages (NRM 2002).

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.

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

It is presumed that the expected total benefit will be achieved in the year the upgrade is completed (that is, 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 six per cent, 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 six percent discount rate. The discounting calculations are presented below.

\[ E(TB_0) = E(B_t) / (1+r)^t \]

and

\[ E(TC_0) = \left[ E(C_t) / (1+r)^t \right] + \left[ E(C_{t-1}) / (1+r)^{t-1} \right] + \left[ E(C_{t-2}) / (1+r)^{t-2} \right] + \ldots + \left[ E(C_{t-n}) / (1+r)^{t-n} \right] \]

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 (that is, 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:

\[ E(TC_0) / E(TB_0) \leq 1 \rightarrow \text{ALARP spillway upgrade required} \]

\[ E(TC_0) / E(TB_0) > 1 \rightarrow \text{ALARP spillway upgrade not required} \]

This calculation illustrates that where the analysis produces a cost to benefit ratio of less than or equal to one (i.e., 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 per cent 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](image)

Assumptions:

\[ P(FE) = 0.04878 \text{ (} = \text{ probability of a 1 in 3000 year AEP event occurring over a 150 year life of the dam)} \]

\[ P(FE)^* = 0.02107 \text{ (} = \text{ probability of a 1 in 7045 year AEP event [equivalent to a 10 per cent increase in spillway capacity] occurring over a 150 year life of a dam)} \]
\[ F = 0.15 \text{ (for medium severity flooding where houses would be damaged during flood events)} \]

\[ PAR = 10 \text{ (obtained from failure impact assessment studies)} \]

\[ VOSL = $5m \text{ AUD (2004 dollars)}^{14} \]

\[ r = 6\% \]

\[ t = 5 \text{ (i.e., upgrade will be completed in year five)} \]

\[ E(TC) = $250,000 \text{ (i.e., expected total cost of ALARP upgrade over five years as follows: year 1: 5%; year 2: 5%; year 3: 15%; year 4: 35%; year 5: 40%)} \]

**Probability of death given dam failure**

Under tolerable safety standard

\[
E(\text{LOL dam life}) = [(F_i \times PAR_i) + (F_k \times PAR_k) + (F_m \times PAR_m)] \times P(\text{FE}) \\
= [0.15 \times 10] \times 0.04878 = 0.07317
\]

After ALARP spillway improvement

\[
E(\text{LOL dam life})^* = [(F_i^* \times PAR_i) + (F_k^* \times PAR_k) + (F_m^* \times PAR_m)] \times P(\text{FE})^* \\
= [0.15 \times 10] \times 0.02107 = 0.03160
\]

**Incremental reduction in probability of death given dam failure**

\[
\text{Incremental } E(\text{LOL dam life}) = E(\text{LOL dam life}) - E(\text{LOL dam life})^* \\
= 0.07317 - 0.03160 = 0.04157
\]

**Expected benefit of ALARP spillway upgrade**

In year 5:

\[ E(B_5) = \text{Incremental } E(\text{LOL dam life}) \times VOSL \\
E(B_5) = 0.04157 \times 5,000,000 = 207,850 \]

At time zero:

\[ E(B_0) = E(B_5) / (1+r)^t = 207,850 / 1.06^5 = 155,990 \]

**Expected indexed cost of ALARP spillway upgrade at time zero**

\[
E(C_0) = [E(C_5) / (1+r)^t] + [E(C_4) / (1+r)^{t-1}] + [E(C_3) / (1+r)^{t-2}] + \ldots + [E(C_0) / (1+r)^t] \\
= 100,000 / 1.06^5 + 87,500 / 1.06^4 + 37,500 / 1.06^3 + 12,500 / 1.06^2 + 12,500 / 1.06 \\
= 198,500
\]

**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 per cent above the tolerable limit to sustain a larger AEP flood event. Had the benefits outweighed the costs however, the upgrade would have been required.

---

\(^{14}\) Assumed based on a figure within the strong to very strong ANCOLD justification range for risks just above the broadly acceptable risk.
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, an additional 21 per cent upgrade would be required in order to satisfy ALARP.
Appendix C—Methodology for interpolating required annual exceedance probability within a particular hazard category using fallback procedure

The following methodology can be applied for interpolating the required annual exceedance probability (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 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:

\[ x = \frac{\log_{10}(\text{Damage}) - \log_{10}(\text{Damage } @ \text{ A})}{\log_{10}(\text{Damage } @ \text{ B}) - \log_{10}(\text{Damage } @ \text{ A})} \]
\[ y = \log_{10}(\text{PAR}/10) \]

Where the values of damages at A/D and B/C have been interpolated from the ranges of damages contained in ANCOLD Guidelines on Assessment of the Consequences of Dam Failure (ANCOLD, 2000) 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 acceptable flood capacity (AFC).

\[
\log(AEP) = \alpha_1 + \alpha_2 x + \alpha_3 y + \alpha_4 xy
\]

where:

\[
\alpha_1 = \text{the log (AEP) of the design flood at point A}
\]
\[
\alpha_2 = \text{the log (AEP) of design flood at point B} - \alpha_1
\]
\[
\alpha_3 = \text{the log (AEP) of design flood at point D} - \alpha_1
\]
\[
\alpha_4 = \text{the log (AEP) of design flood at point C} - \alpha_1 - \alpha_2 - \alpha_3
\]

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 100 km\(^2\)

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.

---

\(^{15}\) Under the ANCOLD Guidelines on Assessment of the Consequences of Dam Failure (ANCOLD, 2000) a 'Medium' level of residential damages corresponds to 'Destroy 4 to 49 houses or damage to a number'.
Point C corresponds to a PAR of 100 and a level of damages equivalent to the destruction of 49 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 $1.0 \times 10^{-4}$ and the AEP of the AFC at points C and D is the probability of the PMP or $1.0 \times 10^{-5}$ (whichever is greater) i.e. $1.0 \times 10^{-5}$.

Thus …

At point A \( y = \log(10) = 1, \ x = 0, \) required AEP = $1.0 \times 10^{-4}$

At point B \( y = \log(10) = 1, \ x = 1, \) required AEP = $1.0 \times 10^{-4}$

At point C \( y = \log(100) = 2, \ x = 1, \) required AEP = $1.0 \times 10^{-5}$

At point D \( y = \log(100) = 2, \ x = 0, \) required AEP = $1.0 \times 10^{-5}$

At the point of interest \( x = \frac{\log(10) - \log(4)}{\log(49) - \log(4)} = 0.366 \)

\( y = \log_{10}(\frac{29}{10}) = 0.4624 \)

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

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

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

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

Which gives a required AEP of the AFC of

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

\[
= -4 + 0 \times x -1 y + 0 \times x y
\]

\[
= -4 - 1 \times 0.4624 = -4.4624
\]

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