ALARP CONSIDERATIONS FOR DAM SAFETY – ARE WE THERE YET?

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ABSTRACT

Are we there Yet? The question we all ask in Tolerability of Risk. The answer is in the journey, which we are all on as owners, regulators or designers.

A number of authorities in Australia are applying risk assessment for the evaluation of dam safety upgrades in accordance with the October 2003 ANCOLD Guidelines on Risk Assessment. A fundamental requirement for the evaluation of risk below the limit of tolerability is the use of the As Low As Reasonably Practicable (ALARP) principle. In making a judgement as to whether an ALARP position may have been reached, ANCOLD suggest the evaluation of a Cost to Save a Statistical Life, good practice, level of existing risk, social concerns, affordability and duration of risk. ANCOLD also suggests consideration of the USBR Criteria for evaluating risk. Recent guidelines on the Acceptable Flood Capacity for Dams developed by the Queensland Dam Safety Regulator provide further insight into the application of ALARP.

The objective of the paper is to make dam owners, regulators and designers aware of some current practice regarding the evaluation of ALARP in Australia, highlight the challenges of applying this principle and to encourage further discussion.

1 INTRODUCTION

As dam owners, designers, operators and regulators, our goal is to produce safe dams. That is, dams which perform their intended functions without imposing intolerable risks to the public.

Because absolute safety cannot be guaranteed, it is necessary to ensure that preventive and protective actions are commensurate with the risks involved. Where risk assessment is applied as a means of managing these risks, the residual risks should be kept as low as reasonably practicable (the ALARP principle). The ALARP principle is a fundamental concept in determining the tolerability of such risks.

The general regulatory approach is to set out the objectives to be achieved and to give considerable choice to owners as to the measures they should put in place to meet these objectives so that the risks are regarded as tolerable. In this context 'tolerable' does not necessarily mean 'acceptable' but refers to a willingness by society as a whole to live with a risk so as to secure certain benefits and in the confidence that the risk is one that is worth taking and that it is being properly controlled. However, it does not imply that the risk will be 'acceptable' to everyone, ie that everyone would agree without reservation to take the risk or have it imposed on them.

The general principle is that the greater the probability of an event and the greater the gravity of the harm should the event occur, the higher is the duty to take precautions, even if these are expensive or difficult to adopt.

The ALARP concept is effectively referred to in a number of Australian statutes, which are designed to protect public safety from hazardous facilities. Additionally, a number of guidelines issued by Australian regulators in a variety of industry sectors refer to the UK Health and Safety Executive (HSE) concept of ALARP, either explicitly or implicitly.

Not all of the guidelines are practical or appropriate for all dams and there are a range of methodologies employed to gauge whether risks are indeed ALARP. This paper explores some of the options available for assessing risks together with examples in the application and evaluation of ALARP with a view to making the reader aware of the challenges in current practice and encouraging further discussion on the subject.

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Risk assessment is still developing and one of the potential future benefits may be that it will enable a comparison of the risk profiles across industry sectors. This ultimately may allow governments to make more informed decisions on the application of public funds.

The ALARP options considered in this paper include:

1. The Health and Safety Executive (HSE) philosophy;
2. The ANCOLD 2003 Risk Assessment methodology;
3. The USBR methodology; and
4. The Queensland Dam Safety Regulator's methodology.

2 ALARP METHODOLOGY AS USED BY HSE

The UK Health and Safety Executive (HSE) provides one of the best developed basic definitions of ALARP for 'duty holders' that is comparatively well documented and has evolved over the past 25 years. It remains one of the most recognized authoritative understandings of ALARP under the British legal systems.

The HSE has developed a coherent framework for the tolerability of risk, with ALARP as the main determining principle. Their efforts culminated in the publication of the developed generic framework in *Reducing Risks, Protecting People*, known as R2P2 (HSE, 2001). HSE has also produced a series of more detailed guides to assist duty holders (owners) and its own inspectors in deciding whether risks are ALARP. These are available on their website.

HSE firstly uses the present situation as the starting point for evaluating ALARP, which is applied to the opportunities for improvement and secondly HSE uses *good practice* as a guide where it exists and is relevant. As pointed out by HSE, a universal practice in an industry is not necessarily *good practice*. In the Australian dams context a two stage approach is used whereby the risk is reduced to at least the '*tolerable region*' and then ALARP is applied beyond this. For risks within the *tolerable region* (lower than the *limit of tolerability* and higher than the *broadly acceptable* level of risk) HSE indicates ALARP should be the determinant of tolerability. Paragraph 124 of R2P2 (HSE, 2001) states:

The zone between the unacceptable and broadly acceptable regions is the tolerable region. Risks in that region are typical of the risks from activities that people are prepared to tolerate in order to secure benefits, in the expectation that:

- *The nature and level of the risks are properly assessed and the results used properly to determine control measures. The assessment of the risks needs to be based on the best available scientific evidence and, where evidence is lacking, on the best available scientific advice;*
- *The residual risks are not unduly high and kept as low as reasonably practicable (the ALARP principle …); and*
- *The risks are periodically reviewed to ensure that they still meet the ALARP criteria, for example, by ascertaining whether further or new control measures need to be introduced to take into account changes over time, such as new knowledge about the risks or the availability of new techniques for reducing or eliminating risks.*

Though HSE expects that this requirement can often be met by just showing that the control measures adopted represent good practice HSE indicate there will be certain occasions where they will expect duty holders to show that the costs of introducing particular options are grossly disproportionate to the risk reduction thereby achieved.

As discussed in paragraphs 101-108 of R2P2, cost-benefit analysis (CBA) offers a framework for comparing the benefits of reducing risks against the costs incurred for a particular option for managing risks. HSE uses CBA to inform its decisions when regulating and managing risks. It does this by expressing all relevant costs and benefits in a common currency – usually money. CBA is normally undertaken for options falling within the tolerable region.

In principle this requires the explicit valuation of the benefit of reducing the risk. However, such a valuation may not always be possible or practicable – in these circumstances HSE rely on qualitative estimates. HSE also apply common sense when reviewing the results. Explicit valuations may not always be necessary because most safety provisions for the day to day hazards they address are in terms of the adoption of 'good practice' or the voluntary pursuit of 'best practice', taking advantage of technological advances; and it may be possible to compare the difference in costs from switching from one option to another against the gains so achieved in terms of avoidance of harm.

Nevertheless, HSE do carry out explicit valuations in support of policy proposals that require duty holders to make major investments in safety measures, or when introducing new regulations.

When an option produces the benefit of preventing fatalities, this requires putting a monetary value on achieving a reduction in the risk of death. For example, for the purpose of conducting CBAs, HSE currently take as a benchmark that the value for preventing a fatality (VPF) of about £1 000 000 (2001 figure). As is made clear in Appendix 3 of R2P2, VPF is **not** the value that society, or the courts, might put on the life of a real person or the compensation appropriate to its loss. This figure derives from the value used by the UK Department of Transport, Local Government and the Regions (DTLR) for the appraisal of new road schemes. However, HSE regard higher values as being appropriate for risks for which people appear to have a high aversion (the practical use of the VPF is discussed further in Appendix 3 of R2P2).

HSE believes that an individual risk of death of one in a million per annum for both workers and the public corresponds to a very low level of risk and should be used as a guideline for the boundary between the *broadly acceptable* and *tolerable* regions.

HSE suggest that an individual risk of death of one in a thousand per annum should on its own represent the dividing line between what could be *just tolerable* for any substantial category of workers for any large part of a working life, and what is unacceptable for any but fairly exceptional groups. For members of the public who have a risk imposed on them 'in the wider interest of society' this limit is judged to be an order of magnitude lower – at 1 in 10 000 per annum.

The main reason that HSE does not determine its decisions on ALARP on the basis of CBA numbers alone, is that it wants the flexibility to weigh the full range of relevant considerations, including societal concerns. Paragraphs 31 to 35 of HSE (2001) make it clear that HSE will consider societal concerns. Such concern may extend beyond risk to life.

The assessment the tolerability of risks is based on the relationship

$$\frac{Costs}{Benefits} > 1 \; x \; DF$$

Where *DF* is the disproportionality factor. It is assessed on the basis of the relative risk with factors ranging from around 2 near the level of 'broadly acceptable' risks up to 10 at the 'intolerable' risk line. However, analyses of HSE decisions have shown that societal concerns can sometimes increase the latter figure substantially.

3 ALARP METHODOLOGY USED BY ANCOLD

The ANCOLD methodology for demonstrating risks are ALARP is detailed in the ANCOLD *Guidelines on Risk Assessment* (ANCOLD 2003). It considers a number of factors in combination with nominated maximum individual and societal tolerable life safety risks. The extent risks are to be below the nominated risk criteria is determined using the ALARP principle.

ANCOLD also indicates risk evaluation is a matter for dam owners, provided the risks meet or are lower than any legal requirements, such as any regulatory requirements.

The risk criteria are different for new and existing dams. One of the factors influencing this was the difficulty in demonstrating lower risks with existing dams with little or no historical knowledge of construction materials and methods.

It is also recognized that satisfying the traditional approach does not guarantee that tolerable risk will be achieved, though that will typically be the case.

ANCOLD is of the view that the following key principles should be observed in judging the tolerability of life safety risks:

- Life safety risks should be reduced below the *limit of tolerability* to the extent that is dictated by the ALARP principle;
- Community attitudes to residual life safety risks should be tested and assured through a process of public consultation.

In making judgements on whether risks are ALARP, the ANCOLD guideline indicates the following points are relevant:

1. Components of the dam should be considered not just the overall dam
2. Cost-to-save-a-statistical-life (CSSL)
3. Whether good practice is met

4 The level of existing risk
5 Societal concerns
6 Affordability is not a consideration for life safety risks
7 Duration that the risk applies may not be a consideration.

CSSL is determined using the relationship:

$$CSSL = \frac{C_A - (E[R:e] - E[R:pr])}{E[L:e] - E[L:pr]}$$

Where:

C_A = annualised cost of implementing risk reduction measure, dollars per annum
E[R:e] = existing expected value of risk cost (failure probability times monetary losses to the owner) for existing dam, dollars per annum
E[R:pr] = expected value of risk cost post-risk reduction, dollars per annum
E[L:e] = expected value of life loss for existing dam, lives per annum
E[L:pr] = expected value of life loss post-risk reduction, lives per annum

Where considered appropriate, the reduction in operating costs can also be included in the numerator.

The ANCOLD guideline requires the reasons for the decision recommendation on tolerability to be documented.

The options for risk reduction just below the *limit of tolerability* are considered using the incremental CSSL between options or the total CSSL from the limit to the risk reduction option and disproportionality reasoning based on HSE type reasoning. This is demonstrated in Table 1 (reproduced from ANCOLD, 2003 Table 8.6). The use of incremental; or total CSSL data for the evaluation of ALARP is open to debate and the use of both data is illustrated below in the evaluation of Dam B.

The ALARP justification is dependent on the proximity of the risks to the nominated *limit of tolerability*. For the same ALARP justification rating when the risks are close to the broadly acceptable level, the CSSL figures are only 30% of those in Table 1.

Table 1 ANCOLD Tentative Guidance on ALARP Justification for Risk just below the limit of tolerability

ALARP Justification Rating	**Range of Cost Per Statistical Life Saved (CSSL) (A$M/Life)**	
	Greater than or Equal to	Less Than
Very Strong	0	5
Strong	5	20
Moderate	20	100
Poor	100	

4 ALARP METHODOLOGY USED BY USBR

The United States Bureau of Reclamation (USBR) uses a two-tier system to measure calculated risks although it may not be the only criterion used to determine necessary dam safety actions to protect the public. The first tier deals with loss of life considerations, whilst the second deals with public trust.

It is understood risk assessment is used to assist on the evaluation of public safety, economic, resource and social concerns within the overall dam safety decision making process. Other factors that may be considered are operational, economic, public involvement, water use, and legal requirements.

USBR define risk as:

Risk = Pr(load) * Pr(adverse response for a given load) * consequences (given response)

Where “Pr” means Probability.

The risks are aggregated over all components of the dam, over all loading categories and over all failure modes to arrive at a single total risk figure.

The first and second tier target risk levels are defined in Guidelines for Achieving Public Protection in Dam Safety Decision Making (USBR, 2003). While Australian practice is to typically evaluate risks for the various components of the dam, the USBR approach is to calculate the risk for each specific loading category (seismic, static, hydrologic, improper operation etc). The evaluation criteria are shown in Table 2.

The USBR criteria are consistent with the insurance industry's approach to insuring against loading events rather than total probability of failure for individual components.

An additional evaluation criteria in use by the USBR is the Annual Probability of Failure, which is totalled for all specific loading conditions seismic, static, hydrologic, improper operation etc. The annual failure probability is evaluated as shown in Table 3, which is taken from Table 1 of the USBR Guidelines.

Table 2 USBR Guidelines to Evaluate Annual Estimated Risk of Dam Failure

Estimated Risk (Lives/yr)	Guideline to Evaluate the Estimated Risk
Risk > 0.01	Justification for taking expedited action to reduce risk.
0.01 > Risk > 0.001	Justification for taking action to reduce risk. Actions can be scheduled into the dam safety program and coordinated with other needs at the facility or at other facilities. Actions should be implemented on a schedule that is consistent with budgeting and appropriate processes. Typically risk reduction should be accomplished within 7 years of decision that risks need to be reduced.
Risk < 0.001	Justification to implement risk reduction actions or conduct additional studies diminishes as estimated risks become smaller that 0.001. Risk reduction action costs, uncertainties in the risk estimates, scope of consequences, operational and other water resources management issues play an increased role in decision making. Actions considered reasonable and prudent should be considered for implementation when the risk is in this range.

It is pointed out that there is a joint requirement within the organisation to ensure public safety for large and more frequent events in the most cost effective way whilst always recognising that employing the most stringent standards still results in some risk of failure.

The risk analysis process is described in two stages, the first in determining the need for risk reduction and the next as evaluating alternative risk reduction strategies. One of the outputs of the process is the prioritisation, that is, priority order and urgency of safety improvement activities in the allocation of limited available resources.

Table 3 USBR Guideline to Evaluate Annual Probability of Dam Failure Estimates

Annual Probability of Dam Failure	Guideline to Evaluate the Annual Probability of Failure Estimate
>0.0001	The justification to implement risk reduction actions increases as the estimates become higher than 0.0001.
<0.0001	The justification to implement risk reduction actions diminishes as the estimates become smaller than 0.0001. Risk reduction action costs, uncertainties in the risk estimates, scope of consequences, operational and other water resources management issues play an increased role in decision making. Actions considered reasonable and prudent should be considered for implementation when the annual probability of failure is in this range.

In relation to risk based and standards based decision making, Reclamation considers that risk assessment is a way of "formalising and documenting" the judgement process which is part of decision making. Since standards are a way of incorporating judgement into a set of design rules, the USBR indicate there must be a level of conservatism to allow for uncertainties. In some cases therefore, an inefficient outcome may be determined leading to significantly different levels of public protection at different dams. However, it is also recognised that where high probabilities of loads and high consequences are the case, then it is necessary to employ the best available technology and build in redundancy in safety improvements to ensure public protection since the reliable estimation of very low failure probabilities may not be feasible.

5 ALARP METHODOLOGY USED BY QUEENSLAND IN ACCEPTABLE FLOOD CAPACITY GUIDELINES

In Queensland, the decision was taken to permit the use of ANCOLD type risk assessments as one of three methods for determining spillway adequacy. The methodology relies heavily on the ANCOLD Guideline (ANCOLD, 2003) but there are a few modifications.

It was recognised that the ANCOLD Risk Assessment Guideline was never intended to be a regulatory document and that some uncertainties contained in the ANCOLD treatment of ALARP needed to be removed for regulatory purposes. This decision was made after consideration of the Queensland dam portfolio:

- Dams are only regulated, from a dam safety perspective, if there is a risk to life in the event of dam failure. Once regulated, the regulator may consider other failure consequences such as economic loss.
- The large variety of dam types and sizes regulated in Queensland range from relatively small farm dams with only one or two houses inundated by dam break floods through to major dams with over 200,000 people at risk.

The regulatory regime therefore had to cope with this wide range of consequences and provide a degree of certainty and consistency in terms of the acceptable levels of risk imposed on downstream communities. In doing so, the Queensland guideline does not discriminate as to whether the PAR includes the dam owner or an employee of the dam owner.

The methodology relies on a Cost Benefit Analysis (CBA) which requires the probable loss of life due to dam failure and the 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[5] and for a range of further potential ALARP spillway upgrades.

[5] 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.

The expected loss of life due to dam failure over the dam's life is calculated by examining the population at risk, the fatality rate[6] and the probability of dam failure during a flood, seismic or other event over the nominated life of the dam[7]. The expected damages due to dam failure over the dam's life is also calculated by examining the property at risk, the damage rate and the probability of dam failure during a flood, seismic or other event.

These calculations 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:

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

$$P(FE) = [1-(1-Pf)^y]$$

Where:

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

$E(LOL)$ = 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 population at risk 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;

Pf = Annual probability of failure for each failure mode with corresponding loss of life

y = lifetime for 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:

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

[6] 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.

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

Where:

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

*E(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);

*PAR_i** = total population at risk 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 probable loss of life from dam failure as a result of the ALARP upgrade being performed may be calculated.

Similarly, the expected damages can be considered by determining the incremental flood damages due to the failure of the dam during an event and the changes to the operations and maintenance costs due to the upgrade. The expected damages are based on *Guidance on the Assessment of Tangible Flood Damages* (NR&M 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 a nominated Value of Statistical Life (VOSL) by the incremental reduction in the estimated loss of life over the life of the dam due to the ALARP upgrade being performed and summing this with the reduction in damages and O&M costs, as shown below.

$$E(TB_t) = E(LOL_{dam\ life})_{Incremental} \times VOSL + E(\text{Damages and O\&M costs}_{dam\ life})_{Incremental}$$

For the purposes of the analysis, it is taken that the expected total benefit will be achieved in the year the upgrade is completed. In this methodology, the VOSL does effectively include an allowance for the disproportionality factor promoted by HSE.

When the cost to undertake the upgrade exceeds the net benefit, ALARP is considered to have been satisfied.

6 APPLICATION OF ALARP METHODOLOGY TO EXISTING DAMS

Three of the above ALARP methodologies have been applied to two existing Australian dams and the results are presented here for comparison purposes.

6.1 ALARP Considerations for Dam A

The dam consists of main and secondary embankments with a primary concrete gravity spillway controlled by radial gates with an auxiliary uncontrolled spillway through a natural saddle into the downstream river reach. Regulator requirements for the state in which Dam A is located are to prioritise improvements to dams in accordance with ANCOLD guidelines, and have particular regard to the ALARP principle. Justification of the ALARP position is the dam owner's responsibility

The risk assessment showed that based on best estimates the risk profile just satisfied the ANCOLD *limit of tolerability* for existing dams. However, as shown on Figure 1, uncertainty analysis revealed that there was about a 20% probability that the risk profile would actually exceed the *limit of tolerability*.

Table 4. Dam A - Summary of Major Failure Modes

Failure Mode	% Risk
Seismic Liquefaction	46.5%
Hydrological Main and Secondary Overtopping	32.9%
Seismic Piping Outlet	0.1%
Hydrological Piping main embankment above level of downstream filter	2.6%
Seismic Piping main Embankment	4.8%
Hydrological Piping secondary embankment	1.4%
Outlet Tower	1.1%
Seismic Spillway Gates & Trunnion	10.4%
Total	99.8%

The dam owner therefore asked the question: "*what remedial works are required to meet* *tolerability criteria and satisfy ALARP?*" A number of options were consequently considered including combinations of the following:

E1 Foundation treatment to address potential liquefaction problems in the main dam embankment and downstream foundation;

E2 Retrofitting of filters to the upper section of the main dam;

E3 Construction of a 1.5 metre parapet wall;

E4 Retrofitting of filters to the secondary embankment.

It was assessed that Option E1 was required regardless of ALARP considerations since the best estimate of the existing risk was close to the limit of tolerability and there was a significant probability that the existing risk lay above the limit. Figure 5 shows that the best estimate of risk is well below the limit when works package E1 is undertaken and below the limit at all confidence levels. Therefore, with works package E1 to be undertaken, and the dam in the ALARP region, the owner then had to assess what other works would be required to achieve an ALARP position.

The risk profile is shown on Figures 2 to 4 for various remedial option combinations. The ALARP assessment leading to the ultimate works recommendation is outlined below.

Of the seven ALARP considerations listed in Section 3 above, the CSSL was straightforward to calculate and assess. However, assessment of some of the other ALARP considerations proved more challenging. A précis of each of these considerations, and their influence on the ALARP decision for this dam are presented below.

<u>Cost to Save A Statistical Life</u>

The estimated CSSL for the proposed works Option E1 was between $206 and $448M, for discount rates from 3% to 8% respectively. The next best package of works (Option E1 followed by E3) had a CSSL in the range from $999M to $2115M. The rating for Upgrade Option E1 was at the margin of "poor", depending on the discount rate. Therefore the works being considered were in the "poor" justification range and on the basis of this criteria alone it was difficult to justify additional works. However, it is emphasised that ANCOLD (2003) states: "The owner can treat CSSL as one consideration, but must ultimately make, and take the responsibility for, the judgement that the sacrifice is grossly disproportionate to the benefit gained in terms of risk reduction."

Other combinations of options were also considered in the light of CSSL. The remedial option E3 for the parapet wall essentially comprises the fallback spillway capacity for a standards based remedial work for which the limiting risk is the annual exceedance probability of the flood given to be about 1 in 379,700 i.e. at this level of annual flooding, which is relatively close to the AEP of the PMP-DF, there is no need to provide additional overtopping flood protection. As the parapet wall would be close to a standards based fix, it might be considered prudent to provide the downstream filter at the same time. However, the CSSL for this combination E1 plus (E2 & E3 & E4) was estimated to be in the range from $1,568M to $3,315M depending on the discount rate, and thus in the "poor" justification range on the basis of the CSSL rating alone.

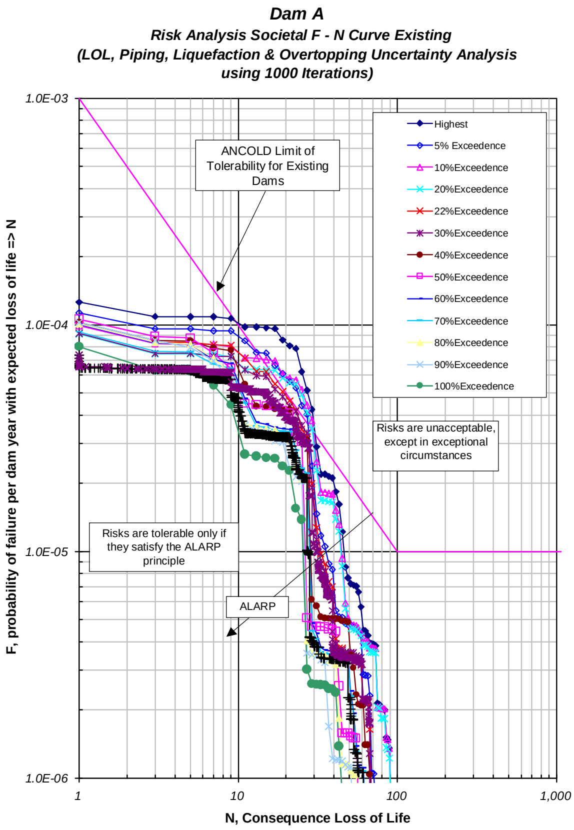

Figure 1 Uncertainty Analysis for Existing Dam A

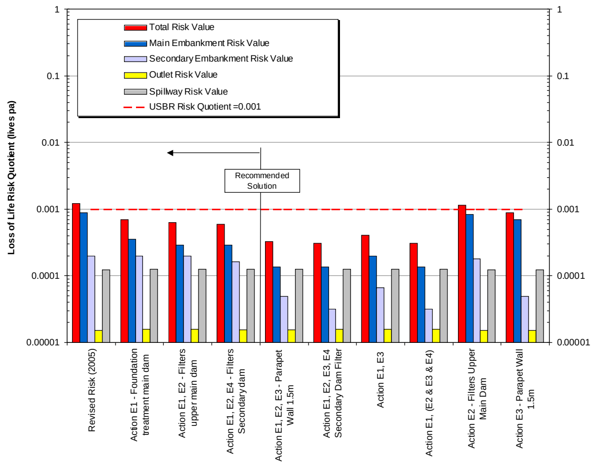

***Figure 2** Dam A Risk Profile for Dam Components*

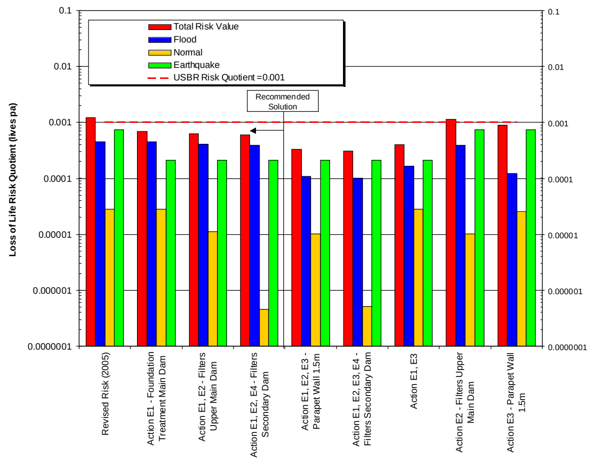

***Figure 3** Loading Risk Profile for Remedial Options of Dam A*

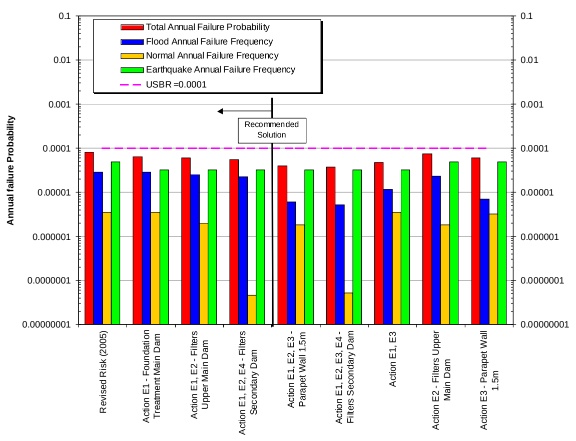

***Figure 4** Existing Dam and Upgrade Options Annual Failure Probability for Loadings*

<u>Components of the dam should be considered not just the overall dam</u>

ANCOLD (2003) proposes two forms of disaggregation of the assessment that should be subject to ALARP justification: on the basis of major components of the dam rather than just the dam as a whole; and on the basis of individual failure modes of the dam and components. For the case study of Dam A, the quantitative risk assessment was undertaken using detailed event trees for each failure mode, and accounting for each major component of the dam thus covering this ALARP consideration.

<u>Societal concerns</u>

ANCOLD (2003) suggests there may be socio-political issues which influence the achievement of an ALARP risk position, such as the strong adverse reaction to incidents involving multiple fatalities, or other circumstances that might make the adverse outcomes appear particularly tragic in the national consciousness.

Whilst the Dam A is highly valued by the regional community, it was not assessed as having a strong position in the national consciousness. However, the nature of the population at risk (PAR) was such that multiple fatalities were possible for non-flood related failures. This is not uncommon for similar dams, but incidents such as the Thredbo landslide illustrate that intensive media and public concern follow any incident involving multiple fatalities, and highlights the issue of "societal concerns". Having stated the above, the assessment was that this dam was not sufficiently different to other dams in Australia to warrant a lower risk target, and thus no adjustment was made to lower the level of risk beyond Option E1 on the basis of this criteria.

<u>The level of existing risk</u>

For relatively low existing risks in the vicinity of "Broadly Acceptable Risk" ANCOLD (2003) suggests that level of risk can influence the assessment of what sacrifice is "grossly disproportionate". That is, if the risks are already very low, the case for further reduction is weaker than it would be at a higher level of risk. For Dam A, the existing risks were very close to the limit of tolerability, so the dam owner decided some level of risk reduction was warranted.

Further , the USBR risk profile charts for the dam components and loadings both show that the total risk following the provision of the remedial works were all below 1x10-3. The loading (flood, normal and earthquake) risk quotients were all below the G-MW interim target level, which was consistent with the USBR criteria. The annual failure probabilities for all remedial options meet the USBR criteria of 1x10-4. This comparison to USBR criteria gave some comfort to the owner that risk reduction actions were appropriate for the level of existing risk.

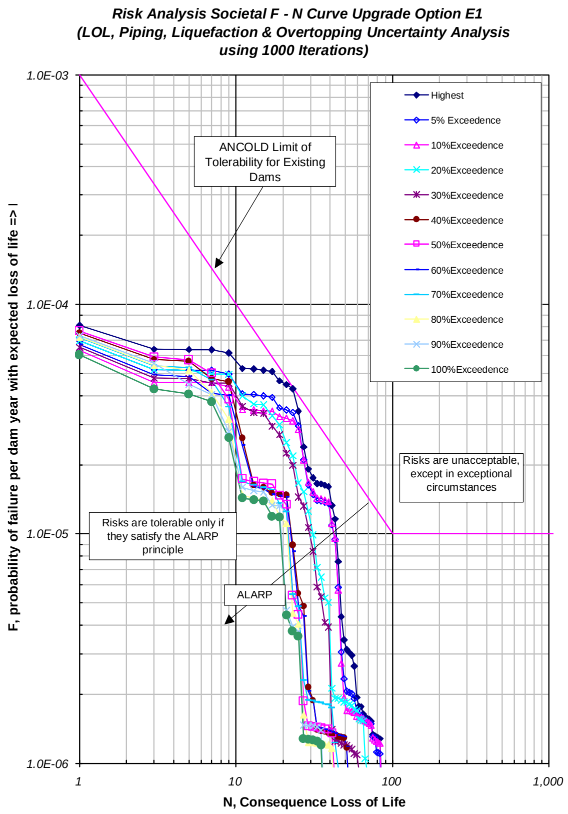

***Figure 5** Uncertainty Analysis for Upgrade Option E1 on Dam A*

Whether good practice is met

A consideration of what is "recognised good practice in Australia" is required by ANCOLD (2003) to justify the ALARP position. However, recognised good practice with respect to risk reduction measures at existing dams is not easy to define, and presents a significant challenge to the decision maker.

An example of works that could be justified under this criterion was the inclusion of filters. If this dam was being built today it would almost certainly have full height filters. However, to assist with their judgment of good practice the owner of the dam drew on the following:

- Owner experience, judgement and precedents from other upgrade decisions within the owner's portfolio;
- Precedent from other Australian dam owners who have engaged in risk reduction works;
- Australian examples of standards based upgrades were considered as a comparison to a risk based approach, and indication of the extent to which owners are prepared to upgrade their structures;
- Judgement and advice of dams engineering consultants;
- Judgement and advice of Australian and international expert reviewers;
- Comparison with design criteria for new dams of a type similar to the case study dam.

The "good practice" consideration had a marked impact on the scope of works ultimately considered by the owner to meet the ALARP requirement. Works package E2 and E4 (filters for main and secondary embankments) had little justification on the basis of CSSL alone, but were included in the risk reduction works scope on the basis of the good practice consideration.

To date upgrade works have been undertaken on four other dams of the owner's portfolio, and the upgrade Options E1, E2 and E4 on Dam A will lower the risk profile in keeping with the remaining dams.

Duration of risk may not be a consideration

ANCOLD (2003) proposes that the temporal effect of risk could influence tolerability decisions. Contrasting examples provided are: (i) where the PAR is exposed to the risk intermittently for short periods; (ii) where they are exposed for a lengthy period, after which exposure ceases (for example construction or modification). Apart from the usual temporal fluctuations, the PAR below Dam A are effectively permanent, so that the duration of risk was not an issue in this case.

Timeframes for Risk Reduction

Another issue that the case study raised was that there was very little guidance on the timeframes within which risk reduction measures should be carried out. USBR suggest three timeframes based on level of risk (refer Table 2): expedited action; within seven years; greater than seven years.

Dependent on regulatory requirements, the ultimate scope of works to achieve an ALARP position for a dam may be staged over time to accommodate the owner's resources and other priorities within their portfolio. However, in this case it is currently proposed that all work to achieve the ALARP position be undertaken as part of one project.

For scheduling upgrades works to Dam A, the owner relied on some internally developed guidance on timeframes within which to achieve risk based upgrades.

ALARP Conclusions for Dam A

Based on the guidance provided by ANCOLD it can be seen that while both the CSSL values and the Cost Benefit Ratios indicated at best, 'poor' justification for remedial works, the uncertainty analysis and ALARP considerations indicated to the dam owner that Option E1 remedial works should be carried out to meet tolerability criteria or the ALARP principle, respectively.

On the basis of the ALARP principle, good practice considerations resulted in Options E2 and E4 (provision of filters to main and secondary embankments) being added to the ultimate scope of works.

Therefore, the scope of works to achieve an ALARP position for Dam A was assessed to include E1, E2 and E4

6.2 ALARP Considerations Dam B

This dam consists of a composite zoned earth and rockfill dam and a zoned earthfill embankment with a dam crest level at 47.2 m AHD. The spillway is a concrete gravity section, which was lowered from 38.2 m AHD to 34.66 m AHD in 2000 in order to reduce the risk. Gates are being added during the current works in order to restore the original capacity and provide some additional storage. The risk assessment for the remedial works showed that, the risk profile for the dam exceeded the ANCOLD limit of tolerability. The design validation modelling confirmed that the dam crest level should be raised 0.8 m in addition to retrofitting filters on the downstream slope and toe drainage using a 5 m deep toe trench. The risk contributions for the existing dam with the spillway crest level at 38.2 m AHD and a number of spillway and filter retrofitting upgrades with varying dam crest levels together with an option for reducing the toe trench depth from 5 m to 3 m in a 2400 m length of the embankment are shown on Figure 6. The objective line shown on this figure was established during prior risk analyses completed for the dam as being a level of acceptable risk to be achieved with the upgrade design.

The consideration of the ALARP ratios is complicated by the fact that it will be possible to raise the dam crest level at a future date if required to pass the PMF while deepening the toe trench requires significant increased costs, if required at a future date. The costs used in the present evaluation were, therefore, based on completing the toe trench during the current works, while the crest raising could be done at a future date.

The CSSL data are shown on Table 6 and Figure 7 and the Cost/Benefit ratios from the Queensland Guideline are shown on Table 6.

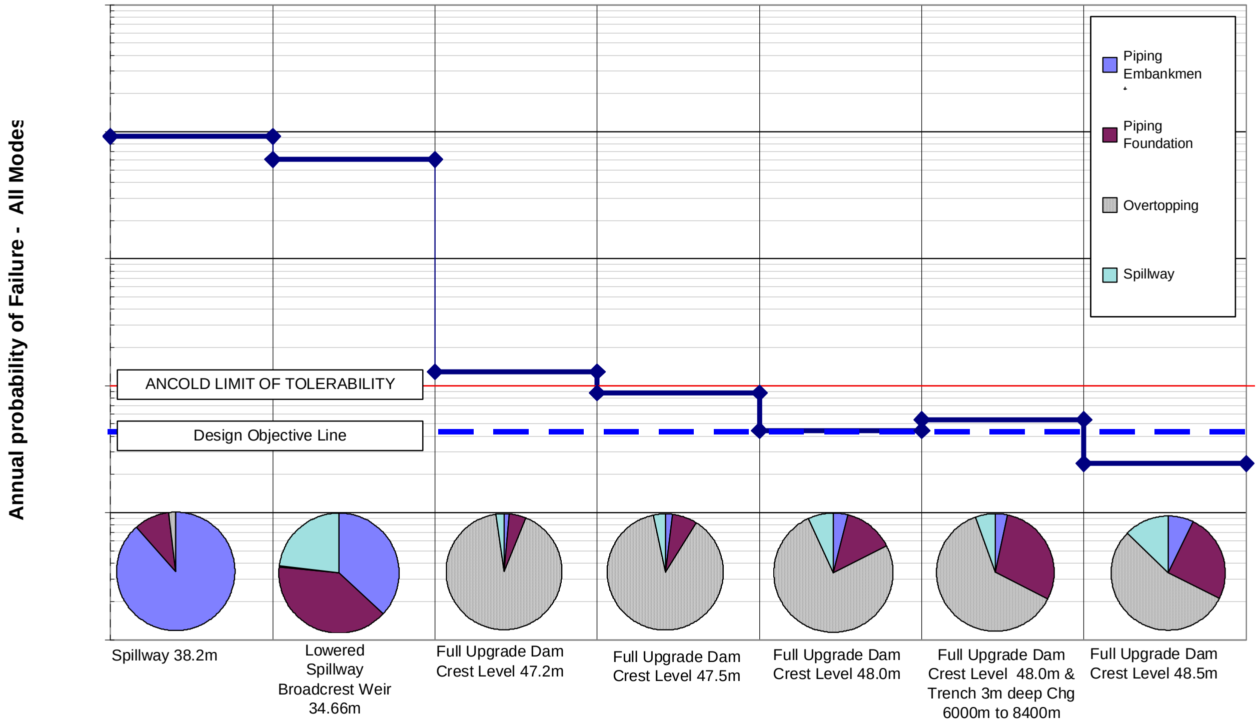

Figure 6 Dam B Total Probability of Failure for various Upgrade Options and Dam Crest Levels

Table 6. Summary of ALARP Results

Description	CSSL $M/Life	ALARP Rating	QLD C/B Ratio
Full Upgrade with Embankment Crest 47.2 m. Satisfies ANCOLD Tolerable Risk Criteria			
Embankment Crest 48.0 m (3 m toe trench Chg 6000 m to 8400 m)	$5.3	Very Strong	0.15
Embankment Crest 48.0 m crest (3 m to 5 m incremental depth of toe trench Chg 6000 m to 8400 m)	$138	Poor	2.24
Embankment Crest 48.0 m (5 m toe trench)	$10.5	Strong	0.23
Embankment Crest 48.5 m	$133	Poor	1.41

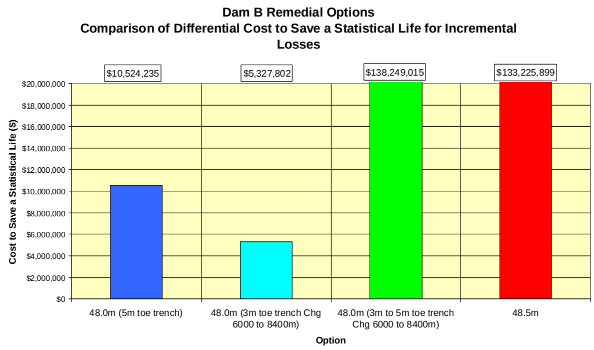

Figure 7 Dam B CSSL Data

The CSSL and C/B ratios clearly show that the embankment toe works provide a positive benefit whether constructed during the present works to the 3 m or 5 m depth in the section from 6000 m to 8400 m. The remainder of the embankment toe trench is 5 m depth.

The incremental benefit for deepening the trench from 3 m to 5 m between Chg 6000 m to 8400 m, however, provides a poor CSSL justification and the cost/benefit ratio is above Unity. Furthermore, the increase in failure probability resulting from reducing the trench depth from 5 m to 3 m is in excess of two orders of magnitude, as shown on Table 7.

Therefore, while the ALARP ratios provided justification for a reduction of the toe trench excavation during the present works from the original design depth of 5 m to 3 m over the length of toe trench Chg 6000 m to 8400 m, sound engineering practice showed that this was not appropriate for this Extreme hazard dam.

Table 7 Piping Probability Increase for Reduction in Toe Trench Depth from 5m to 3m between Chg 6000m and 8400m

Water Level (m)	5m Deep Trench	3m Deep Trench	Pf Magnitude Increase
41.20	3.60E-11	3.60E-11	No Change
43.20	1.98E-10	1.98E-10	No Change
45.20	8.99E-08	8.99E-06	100
47.50	3.96E-05	3.51E-02	900
48.00	3.96E-05	3.51E-02	900

A poor CSSL justification and C/B ratio of less that Unity were obtained for the future raising of the embankment crest by the 1.3 metres required to pass the PMF, which, in accordance with the Draft NRM&W Guidelines on Acceptable Flood Capacity for Dams, is a clear indication that the future raising cannot be justified on economic or life loss basis.

7 CONCLUSIONS

The question of ALARP justification becomes one of what the dam owner and the dam safety regulator (if appropriate) assess is appropriate taking such guidance as they can from sources such as HSE (2001) and ANCOLD (2003).

Dam owners will be responsible for any consequences of the failure of their dams and as such are probably looking for consistency of the results to give confidence that what is being done, or not done, is 'reasonable' and in accordance with the ALARP principle.

Of the seven ALARP considerations, CSSL and Cost/Benefit ratios are the most straightforward to assess as they are determined by inserting the appropriate cost and risk data into a formula, and calculating a value for comparison with published guidelines to determine the justification for the remedial works. The authors caution that, in their experience, CSSL calculations for risks that are below the limit of tolerability often show that any further risk reduction works that cost more than about $1M will show a "poor" justification using the ANCOLD criteria. This highlights the importance of consideration of ALL seven ALARP factors listed in Section 3, prior to making an ALARP decision.

The considerations for deriving an ALARP solution should be independent of the funding. However, it has been noticed in considering packages of works that where dam owners are spending their own money on the project there may be more incentive to accept the risk. However, if the dam owners are being subsidised to undertake the works then they are more likely to be risk averse and undertake the projects as a means of minimising their risks.

From a regulator's perspective, if there was suitable evidence available that the analyses had been performed accurately and diligently in accordance with the minimum standard set in the regulator's stated policy and they satisfied the minimum criteria, there would be little reason to insist on any project being undertaken.

The issue of whether the completed project will conform to standards based designs should not necessarily be an issue for the regulator unless it was a requirement of the regulator's stated policy.

The dam owner's insurers may also have some interest in this process with the more risk being accepted by the insurers, the greater the premiums or a reduced willingness to accept the risks.

The case studies presented have shown that even with detailed quantitative risk analysis in accordance with ANCOLD guidelines, a decision on when the ALARP condition is satisfied is not straightforward. A high level of assessment, analysis, and judgement is required to define the scope of risk reduction works to reach an ALARP position. As stated in ANCOLD (2003), "whilst relevant principles need to be understood, the application of tolerable life safety criteria is not an exercise in mathematics". The authors encourage further discussion on how we assess: "Are we there yet?"

8 REFERENCES

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