Equity, efficiency and protection against tort liability under ANCOLD Guidelines:

the case of the south west irrigation dams of Western Australia

A report prepared by Marsden Jacob Associates
for the Economic Regulation Authority, Western Australia

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TABLE OF CONTENTS

Page

Equity, efficiency and protection against tort liability under ANCOLD Guidelines: the case of the south west irrigation dams

Economic regulation of the prices charged by monopolies is concerned to ensure that costs incurred by a monopoly are both necessary and efficient. In the case of the costs of the six irrigation dams in the south west of Western Australia, the costs of the dam safety program proposed by the Water Corporation are substantial.

In order to understand and address these questions, the Authority has requested advice from Marsden Jacob Associates (MJA) on the flexibility and interpretation of Guidelines produced by the Australian National Committee on Large Dams (ANCOLD).[1] Before addressing this question directly, an overview and perspective on the ANCOLD framework and rationale is required.[2]

Perspective on the ANCOLD Guidelines

The ANCOLD Guidelines on dam safety comprise an integrated set of documents. The core documents relevant to the proposed program for remedial action on the Water Corporation's portfolio of dams are:

a) Guidelines on Dam Safety Management, August 2003; and

b) Guidelines on Risk Assessment, October 2003.

Other documents relevant to dam safety improvement are:

c) Guidelines on Assessment of the Consequences of Dam Failure, May 2000;

d) Guidelines on Selection of Acceptable Flood Capacity for Dams, March 2000; and

e) Guidelines for Design of Dams for Earthquake, August 1998.

Objectives and instruments

Public policy relating to safety generally seeks to advance two major objectives. These are:

- **equity**, i.e., placing all members of society on a (more) equal footing in terms of levels of risk faced, i.e., reducing the disparity in levels of risk faced; and
- **efficiency**, i.e., ensuring that resources and expenditure directed to safety improvements are cost effective and achieve the greatest reductions in risk for each unit of resources committed and expenditure made.

[1] This advice has been prepared by Marsden Jacob Associates in collaboration with David Bowles, Richard Davidson, Len McDonald and Rory Nathan.

[2] The ANCOLD Guidelines have shifted over the past decade from an approach based on specifying engineering standards. A pertinent example of relevant engineering standards is that: *"All dams should have a spillway capacity capable of safely handling the "Probable Maximum Flood"*.

However, the ANCOLD Guidelines have a third objective, namely:

- **protection** (of the dam owner(s)) **against liability**. Thus,

  A dam owner has a legal and moral responsibility to take all necessary measures to prevent a dam failure and to mitigate the effects of a failure should one occur. (Partlett 1988 and others.)[3]

This third objective is largely implicit rather than explicit but permeates the guidelines.[4]

The ANCOLD framework addresses these three different objectives by a partitioned assignment of elements of the framework provided by the Guidelines. These elements are the recommendations to:

- bring risks within the ANCOLD limit of tolerability and thus out of the unacceptable risk region (see Chart 1 and 2);
- prioritise actions to reduce risk;
- reduce risks below the ANCOLD limit of tolerability consistent with the criteria of As Low As Reasonably Practicable (ALARP) principle. For a risk to be tolerable it must be ALARP;[5] and
- apply 'factors of disproportionality' which may need to be observed in the benefits and costs of safety decisions if tort – and possibly criminal – liability is to be avoided. These 'factors of disproportionality' are sometimes inserted into the benefit-cost or cost-effectiveness formula and, therefore, set high thresholds for expenditure to save a (statistical) life where the owner or its directors are subject to legal liability.[6]

[3] ANCOLD (August 2003) Responsibility for Dam Safety and Liability for Dam Failure, Sub-section 2.4.2.

[4] There can be no doubt that the ALARP concept, which ANCOLD has adopted, is directed to the avoidance of liability – that is manifestly obvious from the excerpt from the Edwards vs the National Coal Board case cited in the ANCOLD Guidelines and repeated in this paper (p. 8, below).

[5] The ALARP criterion is a statutory requirement in several states of Australia – examples are Occupational Health and Safety Act (NSW), Major Hazards Facilities Regulation (Victoria) and Dangerous Goods Act (Queensland) – the latter two lean on the UK's Health and Safety Executive (2001) tolerability of risk framework, as does the NSW Department of Planning.

[6] Directors will act mainly to avert criminal rather than civil liabilities.

Chart 1: Revised ANCOLD Societal Risk Reference Guidelines – Existing Dams

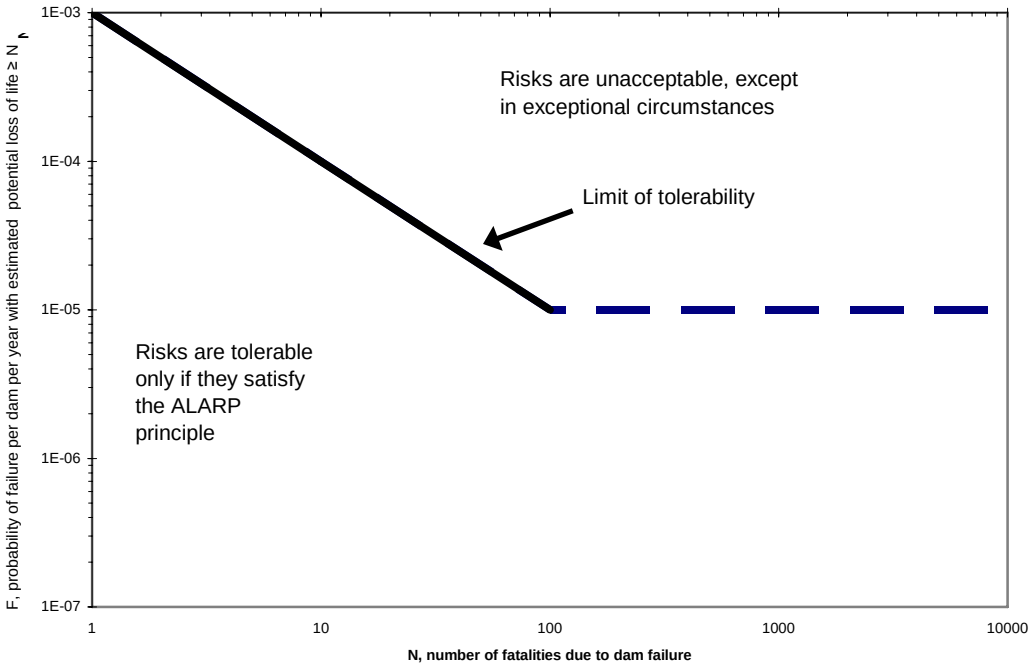
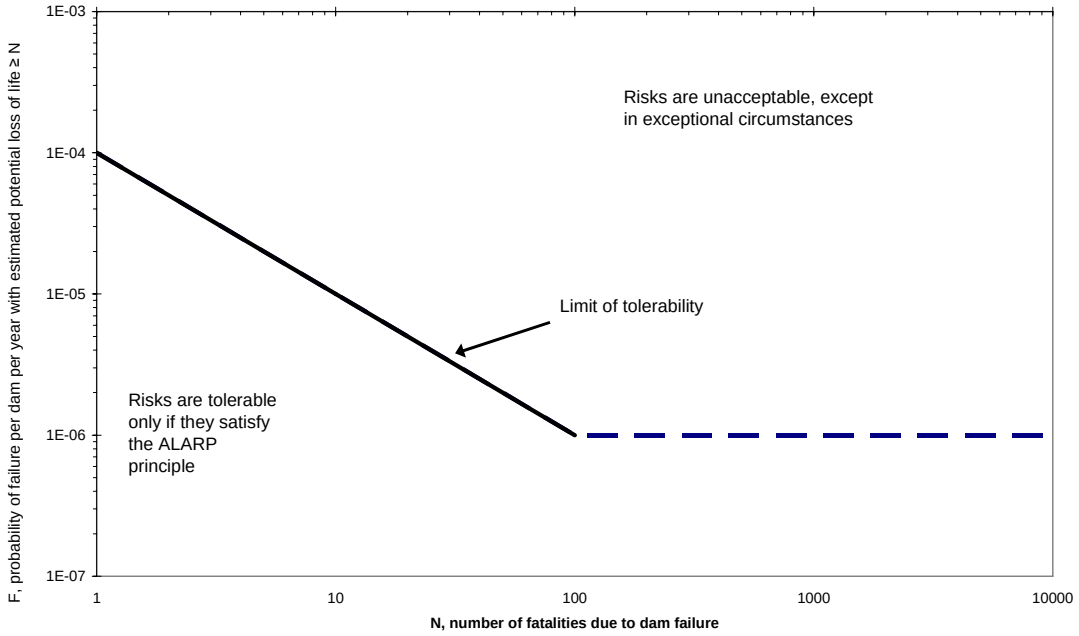


Chart 2: Revised ANCOLD Societal Risk Reference Guidelines – New Dams & Major Augmentations



Notes: 1. The *Greater Than or Equal To* on the vertical axis labels of these charts is incorrectly shown as *Greater Than* in ANCOLD (October 2003). For a continuous probability density function, there is effectively no difference between *Greater Than* and *Greater Than or Equal To*, but F-N plots are estimated as discrete distributions and with these there can be very large differences between *Greater Than* and *Greater Than or Equal To* especially if life loss is not estimated for a wide range of failure and exposure cases (see "Practical Considerations in Developing F-N Curves for Dam Safety Risk Assessment" by Bowles and Chauhan presented at the ANCOLD 2004 Conference).

2. ANCOLD (October 2003) labels the vertical axis by the term 'expected', which could be incorrectly interpreted as the 'expected value' or 'mean' in the statistical sense. We have changed the term 'expected' to 'estimated potential' to clarify that in these figures the meaning of an estimated value of loss of life is intended, rather than the statistical meaning of 'expected value'.

The **equity objective** is addressed by requiring unequivocally that all risks beyond the ANCOLD limit of tolerability be brought down to below the ANCOLD limit of tolerability.

The **efficiency objective** is recognised by allowing other risks to be assessed and addressed on a portfolio basis and by placing limits on the level of cost per statistical life saved to be borne in reducing risks to ALARP. While there is no choice in whether unacceptable risks must be reduced, efficiency criteria can be applied to determine the sequencing and timing of risk reduction actions and expenditures to bring risks down to, and below, the ANCOLD limit(s) of tolerability.

The **objective of liability protection** is addressed by recommending that − in line with tort case law − once risks are reduced to a level below the unacceptable region, the dam owner must reduce risks further unless the costs are grossly disproportionate to the benefits achieved in terms of risk reduction. [7]

ANCOLD limits of tolerability

The ANCOLD framework has largely moved from a standards-based approach to a risk-informed approach which requires that all risks be reduced to tolerable levels. The standards-based approach has effectively been absorbed within a tolerability of risk framework. The limits of tolerability adopted by ANCOLD are essentially international; and are strongly influenced by those of the UK's Health and Safety Executive (HSE),[8] which are endorsed by the UK Treasury.[9] Fundamentally, the limits of tolerability set by ANCOLD and HSE are absolute and have no regard for the costs or benefits of the investment in safety needed to reach them[10, 11]

Chart 3 portrays the HSE tolerability of risk framework in a broad conceptual way.

The ANCOLD Guidelines propose limits of tolerability for both individuals and for societal risks. In contrast, HSE relies primarily on limits of tolerability for individual risk. HSE is very circumspect about societal risk criteria: HSE has not published any F-N criteria[12] and appears to accept the advice of Ball and Floyd (1998) that tolerability limits for societal risk

7 The ANCOLD Guidelines do not distinguish clearly between the application of the ALARP principle as an efficiency criterion and the application of ALARP with factors of disproportionality in order to address the need of many dam owners to avoid tort liability.

8 See especially HSE (1992) Tolerability of Risk and HSE (2001) Reducing Risk, Protecting People (R2P2), paras 118-149.

9 HM Treasury (1996), *The Setting of Safety Standards*, a report by an interdepartmental group and external advisers, June, section 3.3.

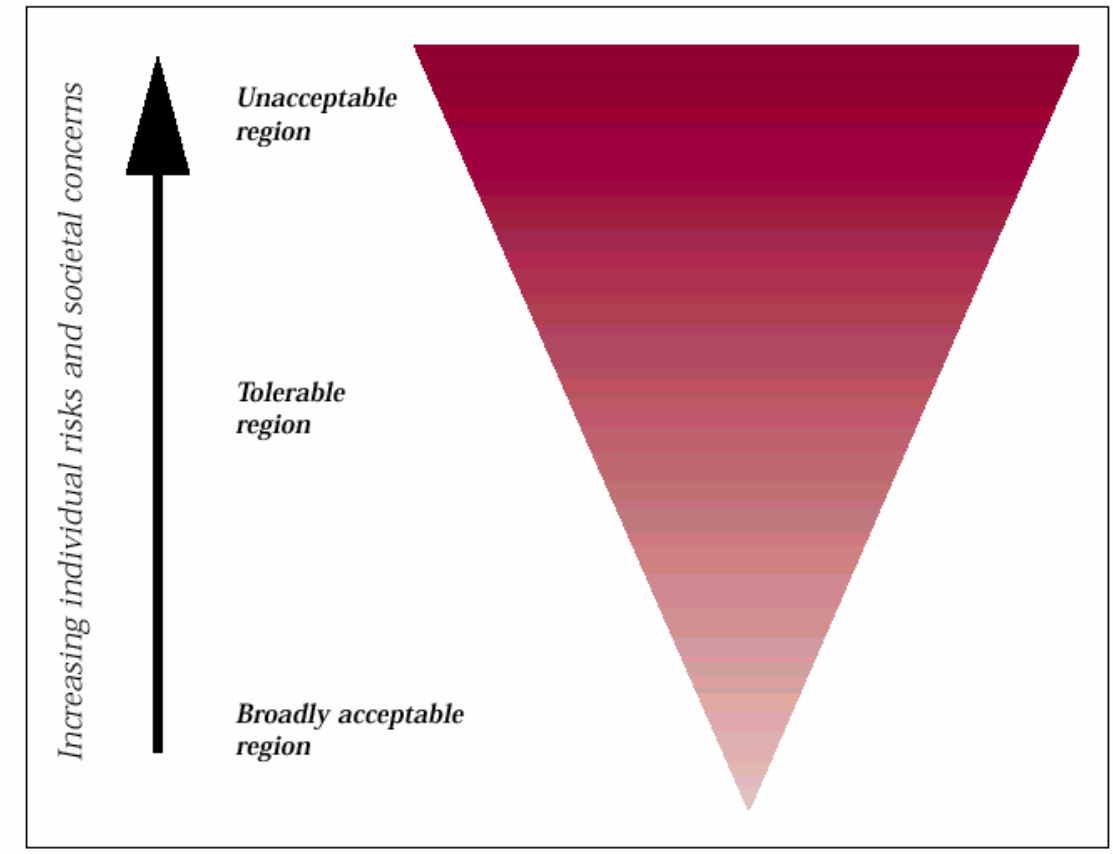
10 The disregard for the costs and benefits of investment in safety when setting the limits of tolerability contrasts with Vrijling (2001) and others who recognise that questions such as "a*re these* [*dike*] *structures safe enough*" requires a broad judgement on the cost of safety expenditures against the reduction of the probability of flooding and the probability of damage. *"However, the general picture is clear. If dike improvement is very expensive a higher probability of flooding will be accepted. On the other hand if the consequence of flooding is very substantial one will aim for a smaller probability."* Vrijling, p.9.

11 See Ball, D.J and Floyd, P.J (1998), "*Societal Risks"*, Final Report, Report Commissioned by the HSE, UK.

12 However, in paragraph 136 of R2P2 it gives a single F-N point criterion of 1 in 5,000 per annum for an event expected to result in the loss of 50 or more lives – we understand this criterion derives from, but is not the same as, the risks accepted at Canvey Island in the Thames estuary as the result of public inquiries.

are controversial and that *"…societal risk criteria should not be used in a 'prescriptive mode' …[but] …should be regarded as no more than indicators or guidelines.*[13]

Chart 3: HSE Framework for the Tolerability of Risk (Figure 1 of HSE 2001)



The fundamental absolutism of the ANCOLD limits of tolerability is, however, diluted in several ways:

a) the ANCOLD limits of tolerability are less stringent for existing dams than for new dams. This difference recognises the higher difficulty and cost of lowering risk in brownfield situations with established infrastructure compared with doing so in a greenfield situation;

b) the truncation of the ANCOLD limit of tolerability of societal life safety risk (risks involving multiple fatalities) for existing dams at levels of life loss above 100 persons to the level applying to 100 persons.

   This truncation is not a feature of the recognised international framework, but is an ANCOLD variation. This variation reflects the view that, given the state of dam technology, it may not be practicable to achieve or to demonstrate risks that are lower than the truncation level;

[13] See Ball and Floyd (1998). Arguably, the limit of tolerability for individual risk would appear to be a stronger community standard to guide the courts than the suggested limit of tolerability for societal risk.

c) the exceptional circumstance 'let out' clause, which recognises that in exceptional cases there will be situations where it is physically impossible or prohibitively expensive to reduce risk to the ANCOLD limits of tolerability but the benefits to society of keeping the infrastructure/assets running are also extremely high. This exception provision is also recognised by HSE; and

d) where there is a portfolio of dams, the risks should be assessed on a portfolio basis and the sequence of actions and expenditure to be undertaken should achieve the fastest and most efficient reduction of risk (see Box 1). This principle is often implicit, rather than explicit, but is widely endorsed, for instance by HSE (Paragraph 114 of HSE 2001) and most recently by the NSW Government.

Subject to these caveats, the need for a dam owner to lower all risks to or below the ANCOLD limits of tolerability is – under the ANCOLD Guidelines – essentially absolute.

Box 1: Assessment and prioritisation of action in portfolios of risks

Portfolio risk assessment (PFRA) is defined by ANCOLD as a particular form of risk assessment or analysis, which aims to make a comparative estimation of risks over all of, or many of, the dams of a single owner or single regulatory or other jurisdiction. Such studies may be limited to the risk analysis phase (the estimation of risks) but more usually entail at least a preliminary assessment of the tolerability of risks, and preliminary identification, analysis and assessment of risk reduction measures, as an initial basis for planning, pending completion of more detailed studies. A similar approach can be applied to compare risks over the several elements and failure modes of a single dam system.[14]

PFRA is a risk-informed approach which can be used to prioritise remedial actions justified on either a traditional standards-based approach or by a risk-based approach.

In Australia, PFRA has been widely applied, for instance, by SA Water (Bowles *et al* 1999), the Water Corporation (Bowles 2000), Goulburn-Murray Water, and many other dam owners. In the USA, the US Army Corps of Engineers (USACE) has trialed a portfolio approach on about 10% of their portfolio of more than 600 dams and is now developing their own approach for application to their entire portfolio with updating tied to periodic dam safety assessments. In the UK, PFRA has been applied to a portfolio of about 150 dams with the acceptance of the owner's economic regulator and linkage to HSE tolerability of risk and disproportionality considerations (Gardiner and Hughes 2005). Other dam owners are planning to follow this lead.

The development of PFRA is coupled with increasing recognition amongst dam owners and dam safety regulators of the ability and need to prioritise actions and expenditures so that the first steps achieve the risk reduction that is focussed on carefully selected goals such as reducing the highest risk or achieving the more cost-effective risk reductions.

A second implication of the increasing application of PFRA is the associated recognition amongst dam safety experts that the biggest gains in public safety are typically made by the first steps and that later steps may produce relatively trivial reductions in risk, i.e., dam safety actions are subject, in the terms of the economist, to sharply diminishing marginal returns, sometimes stated as a small 'bang for the buck' or not being very 'cost effective'.

For the owner of many dams, the first and second implications usually mean that their first risk reduction steps are taken at many different dams and do not result in fully satisfying either engineering standards or long-term tolerable risk levels at each of these dams, but with the intent of implementing additional risk reduction measures at those dams in the future after the more cost-effective risk reductions have been completed. This is in contrast to the traditional approach, often required by safety regulators, of completing all measures necessary to achieve engineering safety standards or long-term tolerable risk levels one dam at a time. Chart 4 illustrates the significantly more rapid reduction in life safety risks estimated for the SA Water portfolio through using the PFRA approach in contrast to the traditional approach.

Recognition of these implications has further led to the formal endorsement (by the NSW DSC and Government) of the concept of continuous improvement and the need to distinguish between long-term and medium-term objectives. (See NSW Government (2006) Risk Management Policy Framework for Dam Safety, Attachment 2, Notes to Principle E.3.)

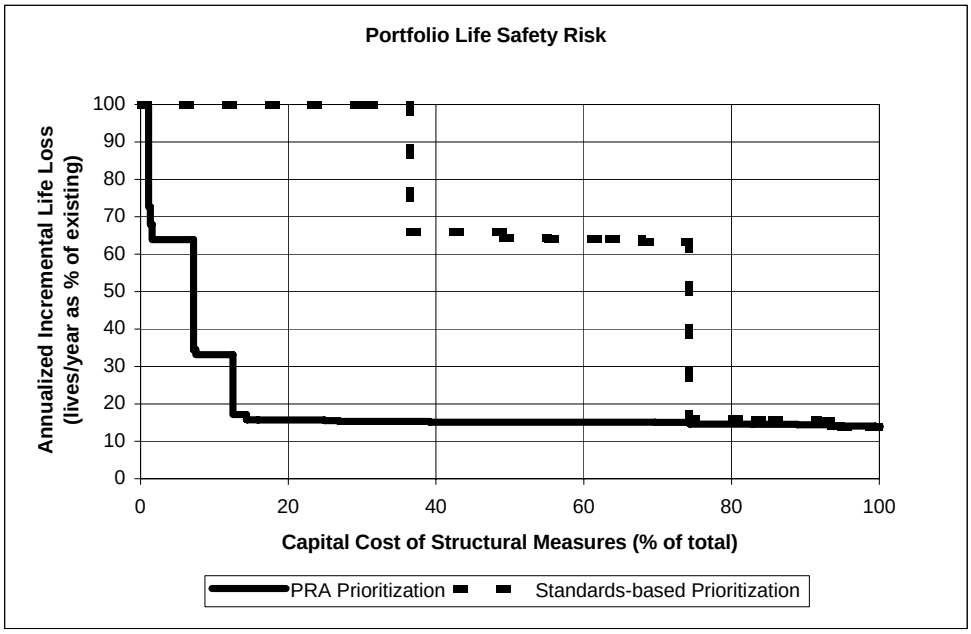
A third consequence of adopting a portfolio view is that attention is turning increasingly to the question of 'which portfolio'. A topical example of the issue of 'which portfolio?' is the current case of the US Army Corps of Engineers, which is considered to be responsible for a portfolio of some 13,700 miles of levees and dikes in addition to a portfolio of over 600 dams.

As demonstrated by Hurricane Katrina where some 1,300 people died, failure of levees and dikes can involve greater loss of life and property damage than the failure of many dams. Should these two portfolios be treated as one in terms of prioritisation and sequencing of remedial actions?

[14] ANCOLD (2003), Guidelines of Risk Assessment, October, p. 139.

Box 1: Assessment and prioritisation of action in portfolios of risks (continued)

Chart 4: Comparison of Estimated Annualised Life Loss Risk Reduction for the PFRA Approach and Traditional Approaches for SA Water's Large Dams (Bowles *et al* 1999[15]).



Should the USACE's combined portfolio of dams, levees and dikes continue to be assessed – and risks managed and reduced – separately from the portfolios of dams that are the responsibility of another US Federal government dam owner, such as the US Bureau of Reclamation?

Similar issues relating to the definition of the relevant portfolio apply in Australia. For instance, should a vertically integrated water business such as Goulburn-Murray Water or SunWater review risks in their dam portfolio on a stand-alone basis, or should their assessments cover the broader portfolio of all risks to life and property in their ambit or other non-third party risks to their business? More broadly, should a government, as the common owner/shareholder of the many separate, legally distinct entities either owning dams or responsible for other infrastructure related risk, define the relevant portfolio on a totally comprehensive basis, especially where the costs and liabilities impact on the government's budget.

ALARP and the objective of protection against liability

As a concept, ALARP is not defined in detail by the ANCOLD Guidelines or in similar guidelines. It can be given operational meaning as a comparison of benefits and costs or as a cost-effectiveness assessment such as the comparative costs of saving a statistical life.[16]

For efficiency purposes these measures are familiar and well known. However, the ALARP principle is applied in the ANCOLD Guidelines in a weighted or leveraged form to afford the dam owner a measure of their degree of protection against tort liability.

The obligations and responsibilities of dam owners are, in common law countries such as Australia, not limited by compliance with regulations or guidelines. In a common law

[15] Bowles, D.S., A.M. Parsons, L.R. Anderson and T.F. Glover (1999). 'Portfolio Risk Assessment of SA Water's Large Dams.' ANCOLD Bulletin, 112:27-39.

[16] Although the HSE (2001) emphasises that such tests should not be the only means of judging that ALARP is satisfied.

system, these merely set the minimum (or necessary but not sufficient) legal requirement. They represent the beginning of the debate over liability. [17, 18]

The ANCOLD Guidelines recommend that dam owners having reduced risks to, or below, the ANCOLD limit of tolerability must further reduce risks to a level "*as low as reasonably practicable*". The operational criteria for ALARP are not specified or described in close detail in the ANCOLD Guidelines – but they clearly involve more than the simple one of comparison of the benefits and costs which would be consistent with the economic objective of efficiency. Specifically, they require that further action and expenditure be made provided the costs are not grossly disproportionate to the benefits. The principle of disproportionality derives from British case law:

> *These definitions appear to derive from the judgement of the English Court of Appeal in the case of Edwards v. The National Coal Board (1949), cited in HSE (2001a), wherein it was held that*[19]*:*
>
> > *"Reasonably practicable" is a narrower term than "physically possible" and seems to me to imply that a computation must be made by the owner in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed on the other, and that, if it be shown that there is a gross disproportion between them – the risk being insignificant in relation to the sacrifice – the defendants discharge the onus on them.*

In the same decision the Court of Appeal also noted that *"…..in every case, it is the risk that has to be weighed against the measures necessary to eliminate the risk. The greater the risk, no doubt, the less will be the weight to be given to the factor of cost."* [underlining added].

Thus, the level or ratio of disproportionality varies with the level of risk and according to HSE guidance on ALARP it generally ranges between a factor of 3 (for risks near to the negligible or "broadly acceptable" level) and 10 times (for risks near to the ANCOLD limit of tolerability) though societal concerns of especially severe consequences are sometimes arbitrarily applied to increase significantly the multipliers, especially the latter one.[20]

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17 In contrast, in countries such as the Netherlands whose system of law is based on the Napoleonic Civil Code, compliance with regulations on dam safety removes further liability. In these countries, compliance with regulations is the end of the debate on liability. For this reason, the limits of acceptability tend to be more stringent in countries operating under Civil Code legal systems than the limits of tolerability in countries operating under common law systems.

For a particularly useful discussion see Ale, B.J.M., (2005) *Tolerable or acceptable: A Comparison of Risk Regulation in the United Kingdom and in the Netherlands*, Risk Analysis, Vol. 25, No.2.

18 The ANCOLD Guidelines present recommendations. It is a separate step to treat them as a 'requirement' instead of just a professional body's 'recommendations'. This step gets into the default role of ANCOLD Guidelines being requirements or their formal regulatory adoption (in some cases with some modification – e.g., NSW DSC). There is also the interesting situation with the WAWC, and some other Australian dam owners, in which they have made meeting ANCOLD Guidelines a corporate commitment, which surely must have some legal implications in itself if they do not meet their own clearly stated commitments. It seems that this commitment would need to be modified to make the changes that are explored or recommended in this report.

19 ANCOLD (2003), Guidelines of Risk Assessment, October, p. 46.

20 The term 'disproportionality ratio' (Bowles 2004, presented at ANCOLD 2003 Conference) – ALARP Evaluation: Using Cost Effectiveness and disproportionality to Justify Risk Reduce. ANCOLD Bulletin 127:89-106. August 2004); HSE (2002a, para 25 - Health and Safety Executive. 2002a. Principles and

The following quotes from HSE documents are indicative:

> *For risks to the public the factor would depend on the level of risk, and where the risks were low (consequence and likelihood) a factor of about 2 is suggested, whereas for higher risks the factor would be about 10 times.*
>
> *For our purposes, it is suggested that a factor of less than 10 in the vicinity of the intolerable* (unacceptable) *region is unlikely to be acceptable and, for hazards that can cause large consequences, the factor may need to be larger still.* [word in brackets added][21]

The ANCOLD Guidelines apply this ratio to derive a range of upper limit costs per statistical life saved beyond which further action/expenditure may be unwarranted. ANCOLD (October 2003) sets this threshold at around $100 million per statistical life saved for risks close to the ANCOLD limit of tolerability (Table 1) based on an adaptation of a similar proposal based partly on regulatory practice in the US context. [22]

Table 1: Tentative Guidance on ALARP Justification for Risks just below the ANCOLD Limit of Tolerability

ALARP Justification Rating	Range of Cost-per-statistical life saved (A$M/life)	
	Greater than or equal to	Less than
Very strong	Zero	5
Strong	5	20
Moderate	20	100
Poor	100	

Source: ANCOLD (2003), Guidelines on Risk Assessment, p.125

Table 2: Tentative Guidance on ALARP Justification for Risks just above the Broadly Acceptable Risk

ALARP Justification Rating	Range of Cost-per-statistical life saved (A$M/life)	
	Greater than or equal to	Less than
Very strong	Zero	1.5
Strong	1.5	6
Moderate	6	30
Poor	30	

Source: ANCOLD (2003), Guidelines on Risk Assessment, p.126

Guidelines to assist HSE in its Judgments that Duty-Holders Have Risk as Low as Reasonable Practicable. www.hse.gov.uk/dst/alarp1.htm) uses the term "proportion factor".

[21] HSE's use of the term intolerable here is arguably, inconsistent with the way that they have defined 'tolerable risk'.

[22] Bowles, D.S., (2001) *Advances in the Practice and Use of Portfolio Risk Assessment*, ANCOLD Bulletin, 117:21-32.

The ANCOLD threshold may be compared with HSE's CSSL threshold of about $(AUD) 25 million (based on a straight exchange rate conversion). This HSE threshold is obtained by applying a disproportionality factor of 10 to the HSE VPF (value in preventing a fatality) of £1,000,000 using the present currency exchange rate (see paragraph 13, appendix 3 of HSE 2001 – R2). The higher ANCOLD figure took account of CSSL values implicit in United States regulatory practice.

Sharply lower thresholds of around $3 million per statistical life saved are set by transportation authorities in both Australia and the US and a figure of $2.5 to $3 million appears to be widely used and accepted in Australia (Abelson 2003) in the areas of public health, roads and other areas of public policy. Above this threshold the road transportation authorities will not consider proposals to reduce road deaths. The sharp difference between these thresholds is consistent with the general absence of tort liability for the infrastructure owner in the case of road deaths compared with the presence of both criminal and tort liability in the case of occupational health and safety and tort liability in dam safety.

Flexibilities under the ANCOLD Guidelines

Against this background, what flexibility is there under the ANCOLD Guidelines in terms of the following:

a) the phasing and timing of remedial actions on dam safety (the "PFRA approach");

b) the ability to widen the portfolio of risks to cover all risks facing the dam owner (the whole-of business approach); and

c) the ability to widen the portfolio of risks to cover all risks facing the ultimate funders, either the customers or the State Treasury (the whole-of-government approach)?[23]

We address these three questions below.

a) In terms of **phasing and timing of remedial actions** on dam safety, ANCOLD already provides flexibility by acknowledging a portfolio approach to dam safety. This flexibility is explicitly recognised in the NSW Dams Safety Committee Risk Management Policy Framework endorsed in August 2006 by the NSW Cabinet. The larger the portfolio of dams, the greater the opportunity to fine-tune the phasing and timing to maximise the reduction in risk achieved by each action and dollar spent.[24]

b) In terms of the ability to widen the portfolio to cover **all risks faced by the entity** owning the dams and to adopt priorities, what should be the phasing and timing to achieve the most efficient path of implementation regardless of the type of infrastructure or source of risk? An important question is whether we must stay

[23] To this list could be added the extent of any latitude in interpretation of the owner's obligations under different levels of strength of justification based on ANCOLD Tables 1 and 2 (the choice of degree of defensibility issue).

[24] This opportunity is further enhanced by the presence of separate failure modes that can be addressed by separable risk reduction measures at an individual dam (e.g., Bowles 1999, Bowles 2001 and Bowles 2006) and the degree to which risk reduction measures can be staged.

focussed on dams alone, or whether the portfolio of risks under consideration can be broadened (see Box 1).

The ANCOLD Guidelines themselves do not appear to consider this question and are silent on this issue. This may be because ANCOLD's remit is concerned solely with dams, but it could be argued that the lack of guidance on this issue undermines the ability of an owner to satisfy the objectives of equity and efficiency across their entire portfolio of risks.[25]

However, state legislation is not silent on the ranking and priority of focus of attention across the wider portfolio of risks. In particular, occupational health and safety (OHS) legislation in most states of Australia now establishes OHS breaches as criminal offences by directors. The intent of this (relatively recent) change in level of responsibility is to set OHS risk above all other risks.

Therefore, where there is a portfolio of risks from multiple sources, directors need to, first, accord priority to OHS and then assign priority to the sequence of actions to address the remainder of the wider total portfolio of risks facing their business.[26]

In assigning this priority, directors and their organisations must be able to demonstrate that they have complied with legal requirements and have acted reasonably. This requires a considered and documented approach to prioritisation and, of course, the timing and nature of subsequent action.

Since the ANCOLD Guidelines are no more than a community benchmark for best practice in one area of risk management, they clearly rank, in priority, below regulatory requirements where the penalties for non-compliance are criminal liabilities. The Guidelines themselves allow a prioritisation within the portfolio of dam safety risks. The process of portfolio risks assessment (PFRA) is a reasonable approach to this. By extension, it may be argued the Guidelines do not preclude a wider PFRA process covering all risks not explicitly covered by legislation.

In summary, while the ANCOLD Guidelines do not directly facilitate consideration of the wider portfolio of all risks facing the dam owner, they do not prevent it.

c) In terms of the ability to widen the portfolio of risks to cover **all risks facing the ultimate funder** (State Treasury). The Water Corporation noted in its submission :

> *From a theoretical point of view, expenditure on risk reduction should be comparable through the economy. Such a comparison should include consideration of whether the levels of expenditure on other risk reduction*

[25] This silence has not prevented expert dam safety consultants from recommending the need for the risk-assessment framework to consider the whole portfolio of assets (and not just dams, even though that was the purpose of the consultancy).

At least one major water business (Goulburn-Murray Water) has begun to move towards formal consideration of all their assets in a 'whole-of-business' risk-based framework.

[26] The remaining risks in the total portfolio will include those for which there is a legislative performance requirement and possibly civil penalties for non-compliance and those where there is no explicit legislative requirement and the sole discipline is the prospective of common law litigation.

> *measures are sufficient. The Corporation would only support such an exercise being undertaken at a whole-of-Government level.*[27]

However, the Corporation also noted :

> *The Water Corporation has a duty of care to maintain dams to current community standards. Community standards in this case have been based on guidelines produced by [ANCOLD].*[28]

The Department of Treasury and Finance note that the threat of liability on directors and officers is a key driver for compliance with ANCOLD.

> *There is no legal requirement for the Water Corporation to adopt ANCOLD guidelines but in the absence of State legislation stipulating alternate standards this is the de facto standard for the Water Corporation.*
>
> *The Board of the Water Corporation choose to meet such standards because it will be held personally liable for any loss of life in the case of dam failure.*[29]

Some obstacles to a broader more flexible approach

A first problem here is the limited charter of each safety regulator, which prevents their taking a whole-of-government approach. Of immediate relevance, the scope of ANCOLD's remit is limited to dams. In a similar way, the NSW DSC has no charter to concern itself with risks other than those arising from dams. These types of limitation in scope apply widely and are a main obstacle to a whole-of-government approach.

Second, the combination of the privatisation and corporatisation of publicly owned utilities plus the introduction of explicit risk standards or guidelines in some areas has created different incentives, drivers and approaches to risk management and reduction from those previously existing in the public sector of each jurisdiction. In Australia, these changes accelerated in the 1990s, with 1994 as a pivotal date for both corporatisations and dam safety standards and guidelines. Thus, the pattern of gaps and differences in approaches to setting formal standards appears to have widened during the 1990s when changes in the governance of many public institutions and instrumentalities occurred.

Corporatisation of publicly owned utilities has therefore become a driver for differential approaches and expenditures on risk, especially loss of life reduction. Thus, some areas of public sector activity (which are both corporatised and subject to direct liability) are now strongly focussed on liability (and risk) reduction, while others (which are non-corporatised and not covered explicitly by risk standards and guidelines) have little incentive other than to muddle through or, in some cases, rely on a whole-of-government approach.

For the objective of minimising corporate liability for risk, there is no doubt that the directors of a corporation, whether privately or publicly owned, will and should take account of the way the courts will attribute liability. This driver is explicitly acknowledged by the Water Corporation in its submission to the Authority.

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[27] WA Water Corporation (2006), *Submission to the Economic Regulation Authority's Inquiry on Harvey Water Bulk Water Pricing*, November

[28] WA Water Corporation (2006) p. 4.

[29] Department of Treasury and Finance (2006), *Submission to the Economic Regulation Authority's Inquiry on Harvey Water Bulk Water Pricing*. pp. 3-4.

If legislation could lift the Corporation's liability, the priority assigned to dam safety would fall, freeing up funds for other capital works with higher priority, potentially including those outside the Water Corporation.

Implications for expenditure and cost sharing

To recap, the existing framework provided by the ANCOLD Guidelines addresses three familiar objectives, namely, equity, efficiency and the protection of dam owners and their directors from tort liability. A key question is: are the costs associated with achieving these objectives, legitimate costs for which the dam owner is entitled to receive the recompense from customers enjoying the services of the infrastructure? A positive answer to this question requires that the costs are both a **necessary** cost of doing business, and that these costs are **efficient**. Efficient costs must be defined in terms of both quantum and timing of expenditures on risk reduction actions, and therefore the magnitude of the costs, especially in present value terms. Efficient costs should not, however, be defined merely in financial terms.

The necessity of meeting the ANCOLD limit of tolerability to achieve the equity objective of placing all members of society on a (more) equal footing in terms of levels of risk faced appears to be a cost of doing business.[30] The Guidelines do not permit, other than in exceptional circumstances, the setting aside of the objective of reducing risks to the ANCOLD limits of tolerability. There may be scope to debate the particular limits set by ANCOLD but the concept of a limit of tolerability appears to be widely and firmly based.

In terms of necessity, the efficiency objective allows prioritisation of actions to move from current risk levels to the ANCOLD limit of tolerability. The efficiency criterion also allows actions and expenditure to lower risks further than the ANCOLD limit of tolerability provided it is efficient to do so.[31] The prioritised expenditures are, by definition, necessary.

Are expenditures to reduce the liabilities of officers and directors necessary expenditures for a business? The short answer appears to be unequivocally yes. The necessity of incurring costs does not however guarantee that the costs are efficient.

A separate question is: are the costs incurred in protecting the entity and its directors and officers from tort liability efficient? This is a more difficult question, but the factors of disproportionality involved in the expenditures to reduce risks below the ANCOLD limit of

[30] In the zone above the '*ANCOLD limit of tolerability'* line – ALARP does not enter the picture – risk must be reduced, the only exception being '*exceptional circumstances'*.

The qualification '*except in exceptional circumstances*' requires explanation. In the view of ANCOLD, the discretion to decide that circumstances are exceptional should not reside with the owner, but should be a matter for government, or for a dam safety regulator acting on behalf of government. The justification for tolerating such high risks is the '*wider interests of society*'. Risks, which would normally be unacceptable, can be tolerated on account of the special benefits, which the dam brings to society. An owner, whilst responsible for the safety of a dam or dams, does not have a charter to act on behalf of society, and is therefore not in a position to make a judgement that such high risks can be tolerated.

[31] It is likely that not all expenditure to reduce risks below the ANCOLD limit of tolerability can be attributed to liability alone. The public's willingness to pay may justify the first increment of further risk reduction and thereafter it may be for liability reasons – in fact this is what the disproportionality ratio shows – a ratio of 1.0 matches the willingness to pay based on VPF, a ratio greater than one is for 1) addressing uncertainties that affect estimates of the achieved level of public safety for which one should err on the side of safety (HSE) and 2) liability and defensibility reasons. A ratio of 1.0 corresponds to the efficient point if we define efficiency in this context as based on the public's willingness to pay.

tolerability can – and should be – assessed by inspection of the information contained in the Corporation's portfolio risk assessments of its total dam portfolio. Since 2004 the Corporation has updated this assessment as new information from design reviews and investigative analysis on specific dams and failure modes has become available.

A separate efficiency issue is the timing of the remedial actions and costs.

Efficiency of timing of actions and expenditures

As noted, a striking feature of the Corporation's planned remedial program for the six south west dams is the very tight timetable, compared with the remedial programs of other dam owners. However, a different timetable would likely emerge if a more effective public policy framework for risk were to be adopted. The flexibility to change this timetable requires either that:

a) the ANCOLD framework is set aside. This is unrealistic and unnecessary and this option is not examined further here; or

b) the ANCOLD framework is set within a broader framework which allows recognition of the wider portfolio of risks facing the Corporation's ultimate owners, the State Government and the people of Western Australia. We term this broader framework the Expanded Portfolio Risk Approach (EPRA).

   Rather than giving essentially immediate priority to reducing the dam safety risks to (or below) the ANCOLD limit of tolerability, priority would be given first to reducing higher risks in a widened portfolio. This widened portfolio could include risks associated with all aspects of the Corporation's business – or more broadly by Government as the owner/shareholder of the Corporation and other utilities and infrastructure including hospitals, road and rail – thus maximising the rate of reduction in estimated potential fatalities and other estimated potential losses in a given period or budget. Changes in timing may not affect the size of the total expenditure on safety upgrades for the six south west dams over the coming decades since, in the long run, all risks are meant to be reduced to tolerable levels. However, the present value of dam safety expenditures would likely be reduced substantially due to postponement of these expenditures.

To achieve this second option requires that:

a) an effective portfolio approach to the wider portfolio of all risks facing government be adopted and implemented by government as has occurred in the United Kingdom; and

b) directors of incorporated water businesses are absolved of legal responsibilities where government directs that other risk reducing actions be undertaken ahead of actions to reduce risk in the water business itself. In turn this would appear to require either, or perhaps both:

   i. legislation establishing a portfolio-wide approach to reducing risks within the state; and/or

ii. a robust mechanism indemnifying the directors of the Water Corporation (and other incorporated state-owned businesses) for no longer being able to give priority only to risks within their control, or alternatively − and more radically − termination of the separately incorporated status of the Water Corporation.

This approach would set a benchmark for best practice and a basis for assessing what total level of efficient costs customers might be asked to share.

Note that 'efficient costs' in this case differ from estimated potential costs not because of any inherent inefficiency in the entity owning the dams, but because of the tort liabilities threatening directors under the current legislative arrangements.

Against this benchmark of best legislative practice toward management of the portfolio of risks facing government, much of the foreshadowed expenditure in the six south west dams might not proceed until other higher risks or risks that can be reduced more cost effectively have been addressed.

The State would still ultimately need to spend most of the $150 million now foreshadowed for the south west dam safety upgrades, but within the medium-term budgetary horizon, some of this amount may now be spent in other areas, depending on the justification for doing so when compared with other risk-mitigation options.[32] Under a legislative framework conforming to the best practice benchmark proposed above, safety expenditures on the south west irrigation dams may be delayed until more effective investments in safety and, in particular in saving lives, are in place. Indeed, under this benchmark policy framework, all expenditures on dam safety would be subject to the same discipline.

The impact of this benchmark policy framework on safety expenditures by the Government can be estimated by examining the updated portfolio risk assessment of the Corporation's dams and the intended remedial expenditures. The Corporation has recently provided a copy of this updated information to the Authority and MJA as the Authority's consultants. However, in principle, it is possible to examine the magnitude of the capital expenditure on risk reduction that would be switched from the dam safety program to other risk reducing safety programs in the State.

This examination would need to consider several scenarios reflecting the different cost thresholds observed in saving a statistical life. Indicative scenarios include thresholds of:

- say, $1 million corresponding to the (assumed) modal value of the cost of saving a statistical life in the areas of, say, health, roads and power distribution;
- $3 million per statistical life saved. Road safety authorities typically have so many low cost investment options for saving lives, which cannot be funded through existing budgets, that they will not consider high cost options involving expenditure of greater than $3 million per statistical life saved. As noted, a figure of $2.5 to $3 million has wide usage in Australia;
- $10 million per statistical life saved; and

[32] However, it is likely that by casting the net more widely to encompass evaluation and treatment of a diverse group of risks would imply an even greater need for capital, and indeed operating expenditures. In addition, the rate of expenditure may be different from that currently proposed and could possibly be either slower or more rapid.

- $100 million per statistical life saved. This threshold is the maximum envisaged in the ANCOLD Risk Guidelines.

These first thresholds are not intended to be interpreted as caps aimed at limiting actions and expenditures to improve dam safety but rather to test how much of the Corporation's remedial program would be delayed if lower cost opportunities to save lives were to be taken first.

Table 3: Allocation of Safety Expenditures Between Dams and Other Areas of Risk Under Current Legislation and New Legislation for Better Management of Risks Facing the WA Community

Scenario	Safety Expenditure		Change	Total	PV of costs to be shared with Harvey Water
	Dam Safety Program		Road Safety Hospital & other areas		
	6 South West Dams ($ million)	All 90 dams			
Current legislation	150	100			102
New legislation with threshold of					
$1 million/SLS	90	40	160	250	20
$3 million/SLS	70	50	120	250	30
$30 million/SLS	95	60	95	250	60
$100 million/SLS	100	70	80	250	90

Note: The inserted figures in this table are purely indicative.

The approach indicated in Table 3 says that a life saved on the roads is to be counted equally with one saved downstream of a dam. This is not the outcome of the current 'silo' like application of the ANCOLD Guidelines.

Arguably this alternative approach is reasonable: in Western Australia, people die on roads every day of the week, and people appear to have died in two of the past three years as a result of bushfires associated with electricity distribution. In contrast the latest person to die in Australia from dam failure died in 1929.[33]

This 'silo' like application is dictated by the combination of the narrow approach to safety regulation / guidelines and the lack of effective mechanisms to protect the Corporation's directors from tort liability if they were to delay dam safety remedies in order that other more cost-effective safety measures be taken elsewhere in Government.

The approach of treating a life as a life puts aside the frequently held views that there are very different qualities of risk and death and that safety and risk policy should respond to these differences in quality.

[33] Moreover, in the process of improving dam safety a number of people have been killed. For instance, there were three deaths at Burrinjuck dam alone. This illustrates that reducing risks creates other risks.

Discussion

The view that some risks justify a higher level of public expenditure than others has support in submissions made to the Economic Regulation Authority in this review:

> *The Issues Paper suggests a possible approach involving the establishment of a benchmark for the level of expenditure that is required to prevent a fatality. This approach appears to be very narrow and ignores a number of fundamental issues associated with contemporary societal risk…. (S. Fox, p. 1)*

One such factor is a possible aversion to multiple fatality risk. On this, the same submission suggested that:

> *In general society has a bias against rare events with high consequences compared to more common events with lesser consequences. To illustrate compare the attention given to improving and maintaining an impeccable aircraft safety record in Australia to the tolerance of our current road safety record… (S. Fox, p. 1)*

A second factor suggested as justifying a higher level of public expenditure on some risks is the nature or 'quality' of the risk.

> *Australians appear to have a higher tolerance for risk that is self imposed compared to a risk that is imposed upon them by others. For example people often choose to engage in high risk activity (such as smoking cigarettes) knowing that they have a statistically greater risk of reduced lifespan, but would react strongly against the construction of a hazardous waste incinerator adjacent to their homes if an absolute guarantee of zero health impacts cannot be given. (S. Fox, p. 2)*

The Corporation submission makes a similar point:

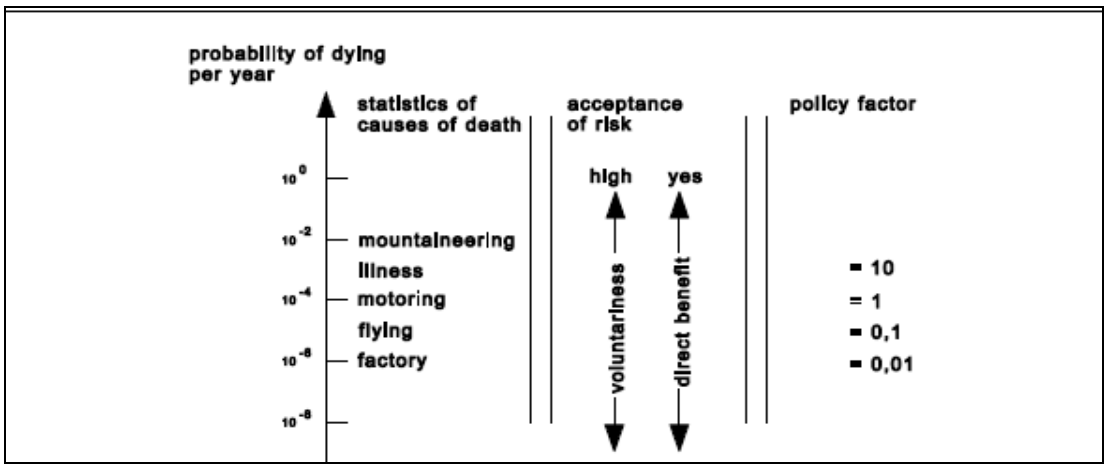
> *Communities do not generally take a simple equivalent cost of life approach to safety expenditures. Consideration is given to factors such as the choice the individual has in exposing themselves to the risk and the size of the potential loss of life. (Corporation submission, p. 8)*

The UK Government has sought to examine these issues systematically and the work of Dutch safety experts should also be noted.

Vrijling suggests that the tolerated risk of fatality varies along a spectrum and is highest for those risks that are self-imposed or where the activity provides a direct benefit (such as mountaineering or bungee jumping) and lowest for those risks that are less voluntary and provide less direct benefit.[34] Vrijling proposes that the relativities between these risks reveal community preferences for different risks and that these relativities are relevant to safety policy. In addition to preferences, such relativities will reflect much more than community preferences towards risk; in particular they will reflect the costs and availability of technological options for risk reduction.

[34] Vrijling J.K. (2001), "*Probabilistic design of water defense systems in the Netherlands*", Reliability Engineering and System Safety, Vol. 74, No. 3, pp. 337-344.

Chart 5 : Personal Risks in Western Countries Deduced from the Statistics of Causes of Death and the Numbers of Participants per Activity



Source: Vrijling, J.K., (2001) *Probabilistic Design of Water Defense Systems in the Netherlands*, Reliability Engineering and System Safety, 74, pp. 337-344.

The strength of the rationale for weighting different 'quality' risks more highly in terms of tolerability limits is examined by the UK Treasury and in the more detailed review by Ball and Floyd (1998).

On the question of whether society has an aversion to multiple fatalities, as distinct from the same number of fatalities occurring in single events, the review of societal risk by Ball and Floyd, which attempted to examine the available evidence on risk aversion, concluded:

> *Though the documented evidence is sparse, nowhere have we found any compelling support or arguments for an ex-ante stance other than risk neutrality in societal decision making.*[35]

More specifically, they observed:

> *… there is very little evidence for differential risk aversion by the public where this is based on number of fatalities.*

However, Ball and Floyd go on to suggest that:

> *there is at least a hint that from the French study, and also the Dutch societal risk criteria which emanated from the Dutch political system (Vrijling* et al, *1995) that elected officials, senior administrators and risk managers may be averse to major accidents. That this group should be averse to high consequence accidents is hardly surprising, but whether this is attributable to enlightened self interest or to a professional assessment of the wider consequences of such events for society, is less easy to discern.*[36]

A further concern with these 'quality issues' is that their initial appeal is not matched by any tangible index or measure. Thus Ball and Floyd (1998) suggest that:

[35] Ball, D.J and Floyd, P.J (1998), "*Societal Risks*", Final Report, Report Commissioned by HSE, UK.

[36] Ball, D.J and Floyd, P.J (1998), p.22.

> *Concepts such as 'dread' for instance, appear to have outlived their usefulness, providing little constructive input to the decision process. And other measures such as willingness-to-pay, also present difficulties to the unwary.*[37]

Another concern/criticism of the weighting schemes sometimes developed to reflect differences in the quality of risk is their essential arbitrariness. Thus, while the UK Treasury observes that:

> *"It is also common for maximum acceptable levels of arbitrary factors of 10, for hazards which are considered to be especially undesirable or politically sensitive."*

the Treasury also notes that:

> *"There is no … rationale for the much tighter limits applied to certain kinds of risk, often because they are politically sensitive. It is possible that considered public preferences, as distinct from instant gut responses, would favour tighter limits to risks of this kind, although there is no evidence of this."* [38]

There appears to have been only one major empirical study into community perceptions of dam safety in Australia.[39] The respondents of this CSIRO survey indicated that, when compared with 19 other risks such as traffic accidents, medical error and bushfires, the lowest of concern in both the short and the long term was dam failure. Similarly, respondents indicated that dam safety was the lowest priority area for government spending. These results were particularly strong for Western Australia, where the level of expenditure was described by respondents as approaching "too much".[40] The study concluded that *"…dam safety is not a highly salient issue in the community, even where upgrades have been discussed",*[41] this being despite the fact that respondents saw dam safety as an involuntary risk affecting a large number of people.[42]

On balance, the evidence on arguments in favour of giving different qualities of risk different weightings appears to be mixed. In addition, the arbitrariness involved in operationalising these weightings is difficult to justify when it means that more lives are lost than would be the case if these weightings were not applied. This perverse result follows because the weighting schemes are designed to ensure that greater protection is applied against some qualities of risk rather than providing protection on the most efficient basis in terms of saving lives or reducing other consequences.[43]

Finally, even if considered that involuntary risk and consequence warranted higher and more stringent standards or guidelines than risk voluntarily accepted, there appears to be a sufficient volume of involuntarily imposed risks to warrant a EPRA approach even if limited

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37 Ball, D.J and Floyd, P.J (1998).

38 HM Treasury (*1996), *The setting of Safety Standards,* a report by an interdepartmental group and external advisers, June, section 3.3.

39 Syme, G.J. and Bishop, B.J. (1992), "Community Perceptions of Dam Safety Issues: A Preliminary Study. CSIRO Division of Water Resources Consultancy Report 92/32 to the NSW Dams Safety Committee.

40 Syme, G.J. and Bishop, B.J. (1992), p.19.

41 Syme, G.J. and Bishop, B.J. (1992), p.71.

42 Syme, G.J. and Bishop, B.J. (1992), p.25.

43 A Harvard Risk Management Centre newsletter referred to this as 'statistical murder'.

to this category of risk. For instance, deaths to passing motorists caused by the collapse of mid-highway high voltage cables do not seem to differ in nature from deaths resulting from bushfire or an earthquake induced collapse of a dam.

A closely related point is that, key factors determining the 'quality' of a risk such as 'voluntariness' and 'benefit' of an individual from enjoying the particular activity or service, appear to be already recognised in the system of legal liability in a country such as Australia, which operates under the common law system. [44] In contrast, say, the Netherlands, which operates under the Civil Code of Law, operates under a legal system whereby compliance with the law provides protection against further liability.[45]

Chart 5 (p. 18 above) is taken directly from Vrijling (2001). For the Netherlands, a country operating under the Napoleonic Civil Code of Law, Vrijling, as already noted, suggests that the gradation between high voluntariness and high benefit on the one hand to total imposition and no benefit on the other should be reflected as 'policy factors' in the system of safety regulation/guidelines. However, in a common law country, the same chart allows a different interpretation whereby the final column of the chart could indicate the different likelihoods of tort liability.

Traditionally at least, fatalities in mountaineering do not result in tort liability cases – unless there is gross negligence. On the other hand, tort liability has been, and remains, a common feature of fatalities and injury in the workplace. Between these two extremes and correlated with factors such as voluntariness, benefit and control there is a spectrum of increasing likelihood of tort liability.

The absence of tort liability means that 'quality' factors such as voluntariness and benefit – if they are to be reflected – need to be reflected in the regulatory standards and risk guidelines. Common law countries need to be careful not to have double recognition of voluntariness, benefit and control in the acceptance of risk.

For the purpose of protecting a dam owner against legal liability, the 'quality' of risk issues may justify high thresholds of expenditure to save a statistical life. They do not, however, justify different limits of tolerability or a narrowly focussed drive down to beyond those limits for a particular sub-set of risks, particularly when deaths and other consequences in the wider portfolio of risks can be reduced more efficiently and with greater equity. This does not deny that different approaches to risk management will differently affect different groups of individuals and organisations.

Moreover, as stressed by Viscusi,[46] if society spends too much in reducing life lost in one area of risk, it is likely to be increasing life loss in another. Specifically, Viscusi suggests that safety expenditures above a certain threshold, say, $US 100 million for the cost of saving a statistical life will result in a net increase in fatalities.

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44 Voluntariness/benefit/control issues, as in Vrijling (2001), played a significant part in the thinking of ANCOLD on CSSL thresholds.

45 Ale notes that: *"The risk criteria adopted in the United Kingdom and the Netherlands looks very similar. Both countries have upper limits for 'allowable' individual risk and both countries use criteria lines in FN curves. Even their numerical value does not differ a great deal. However, the interpretation differs greatly. Whereas the criteria in the Netherlands are the end of the discussion, in the United Kingdom they are the starting point."* (Ale, B.J.M. (2005) *Tolerable or acceptable: A Comparison of Risk Regulation in the United Kingdom and in the Netherlands*, Risk Analysis, Vol. 25, No.2).

46 Viscusi, W. Kip, (1996) "*Rational Risk Policy*", The Arne Ryde Memorial Lectures, chapter 7.

Recommended framework

The outcome of the EPRA approach to reducing risk of fatality from publicly owned infrastructure in Western Australia would be as follows:

- State resources available to reduce estimated potential fatalities and other major risks would be used much more cost effectively. The most cost effective actions would be undertaken first since the CSSL is largely determined by the level of risk pre-improvement this will generally mean tackling those extreme risks (and consequences) first, i.e., risks lying in the extreme north or north east corner of the diagrams showing individual and societal risks, respectively;[47]
- the ethical or equity objective reflected in the ANCOLD limit(s) of tolerability remain in place. Their long-term relevance is unchallenged. Indeed, these ANCOLD limits of tolerability become relevant as an objective to each risk in the widened portfolio of risks;[48]
- both equity and efficiency will be better promoted by recognising that the ANCOLD limits of tolerability are broadly applicable to all types of risk. Moves to lower risks to, and beyond, these ANCOLD limits should apply across the extended front of risks while ensuring that the maximum level of risk reduction is achieved at each step. This approach contrasts with the current situation which aggressively attacks one subset of risks to the exclusion or detriment of progress in reducing life loss and other risks in other areas; and
- this EPRA approach offers a better outcome: for the community since there is a greater reduction in estimated potential life loss for the same level of expenditure; for the Government since its expenditures are both more efficient and more equitable across the community; and for the irrigators represented by Harvey Water since they would no longer be asked to share the ultimate full costs prematurely – under this broadened framework and definition of portfolio some costs may optimally be delayed since not all safety improvements would command priority in the short to medium term.

The recommended framework (*Expanded Portfolio Risk Approach)* provides a rational approach that affords greater flexibility to ensure that life safety risks are reduced in the more efficient and equitable manner.[49]

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[47] Existing risks in the NE corner are not necessarily those that can be reduced most cost-effectively. In addition, although Bowles has advocated the use of cost-effectiveness in prioritising risk reduction options, he has at the same time advocated for the use of probability of life loss to prioritise high existing risks. To overlook this combination of approaches is to overlook the distinction between archiving the equity goal 'ANCOLD limit of tolerability' (the immediate NSW DSC goal in their progressive approach) and the long-term goal of deciding how much further to reduce risks to satisfy ALARP. Perhaps a key issue is whether to recommend backing off on the urgency of achieving the equity position/ANCOLD limits of tolerability.

[48] In the ANCOLD context the limits of tolerability are not the ultimate objectives, the ultimate objectives are satisfying ALARP, which in general is a level of risk below the limits of tolerability.

[49] The recommended framework does not resolve the conflict and tradeoff between the objectives of efficiency and equity but should allow a more efficient tradeoff. In general, investments to achieve the equity gaol will be less than optimal in terms of maximising cost effectiveness – one has to make a tradeoff or decide, as the NSW DSC has, that equity comes first regardless of the effects on efficiency.

ELICITATION AND REVIEW WORKSHOPS IN RISK ANALYSIS FOR DAMS

Background

Research has shown that the judgments of specialists, even eminent experts, do not have particularly good reliability in predicting outcomes but the mean prediction of several experts can be good [Jones, J C, *An Independent Consultant's View on Risk Assessment and Evaluation of Hydroelectric Projects*, Proceedings of the International Workshop on Risk Analysis in Dam Safety Assessment, National Taiwan University, Taipei, Taiwan, 14-15 June 1999 and Hynes, M and Vanmarcke, E, *Reliability of Embankment Performance Prediction*, ASCE Engineering Mechanics Division Specialty Conference, Waterloo, Ontario, Canada, 1976]. This is one thought behind elicitation workshops in risk analysis. Another consideration is that the process of challenge and debate among experts improves the group understanding of the issues and promotes more reliable outcomes. Finally, the bringing together of several highly experienced people greatly expands the knowledge and experience "database". Often a review function can be incorporated into elicitation workshops, though separate workshops for review are feasible.

Process

Elements of a good workshop process are:

1. a facilitator who will keep the group focussed on the issue at hand, will ensure that the views of all participants are considered and will manage the reporting of the outcomes;
2. several highly experienced expert participants, ranging from those with general dams engineering experience to specialists in such areas as hydrology and geotechnical engineering, and including one or more persons who understand probability theory;
3. the risk analyst(s) who have undertaken work on the dam to date;
4. the dam owner is represented, both at a senior level and at dam operator level [no one knows the dam as intimately as the operator];
5. work to date has been documented, including the reasoning in support of the outcomes;
6. work to date has been subjected to normal quality assurance procedures – workshops do not have a verification role;
7. risk estimates will be supported by analysis wherever practicable;
8. each risk estimate will be debated;
9. where there is a difference of opinion, the reasons for the difference will be elucidated – hopefully leading to a convergence of opinion, but if consensus is not reached the basis for the alternative opinions should be identified and they should be considered in the risk analysis unless further analysis or investigation can provide the basis for a consensus position;
10. there should be agreement on the additional work to be undertaken before the risk analysis moves to the next phase;
11. the participants discuss and reach agreement on key aspects of the next phase of the study; and
12. the outcomes of the workshop should be documented and the report signed off by all participants, with or without dissenting opinions.

Timing of workshops

Timing is variable according to the nature of the risk analysis and the purpose of the workshop – elicitation or review or both. However, it is widely agreed that it is unsatisfactory to complete an analysis and hold a review workshop at the end of the study. The idea is that workshops are held at key phases as the work progresses. Typical workshop points are:

1. upon completion of hazard analysis and failure modes/mechanisms analysis – load states and the logic of failure mechanisms need to be signed off before the analysts attempt to quantify conditional probabilities;
2. when probabilities of failure are completed;
3. when failure consequences have been estimated and the overall risks assembled; and
4. if needed, a later workshop to consider the risks after implementation of safety improvements.

When elicitation and review are combined, the workshop:

- reviews work done to date and identifies changes to be made or additional work to be done;
- elicits from the participants the judgments needed to define and guide the next phase of the study.

1. RISK ANALYSIS FOR DAMS

What is risk analysis?

Risk analysis is defined [in part] this way by ANCOLD:

The use of available information to estimate the risk to individuals or populations, property or the environment, from hazards (qv). Risk analyses generally contain the following steps: scope definition, hazard identification, and risk estimation.

Risk analysis typically involves the generation of the following quantitative risk values for each of several to many dam failure scenarios:

1. probability of dam failure;
2. probable loss of life [PLL]; and
3. dollar losses from dam failure.

Other consequences of dam failure, usually regarded as incommensurable, intangible or otherwise incapable of quantification, are weighed qualitatively.

Process

Risk analysis for dams is set out in the *Guidelines on Risk Assessment* [ANCOLD October 2003]. The key steps are:

- **Identify the context**
- **Identify hazards**

  For dams, the most common hazards are floods, earthquakes and internal flaws.
- **Undertake failure modes analysis [FMA]**

  Failure modes and mechanisms are identified and are usually described by logic systems such as event trees and fault trees. The common failure modes for dams are overtopping, excessive load due to flood, instability, liquefaction due to earthquake shaking and piping [internal erosion] initiated by internal flaws, flood or earthquake.
- **Define load states**

  Definition of several to many load states facilitates the estimation of system response.

  [Workshop point – see box]
- **Estimate system response**

  Given a load state or initiating condition, the conditional probability of dam failure is estimated, usually with the aid of event trees or fault trees. Estimation is based on experienced judgment, assisted so far as practicable by quantitative analysis.
- **Estimate probability of failure**

  [Workshop point – see box]
- **Estimate probable loss of life [PLL]**
- **Estimate dollar losses**
- **Compute risks**

  Risks are typically estimated for life safety, economic and financial losses, environmental losses and intangible impacts. They are reported in any relevant ways – by dam component, by hazard, by failure severity.

  [Workshop point – see box]
- **Document the analysis**

  Whilst this is listed last, it is actually done progressively through the analysis.

2. PROBABILITY OF PIPING OF AN EMBANKMENT DAM

As the result of research, there is now a structured *event tree* method for estimating the probability of piping failure [Foster, M A, Fell, R, Davidson, R and Wan, C F, *Estimation of the Probability of Failure of Embankment Dams by Internal Erosion and Piping Using Event Tree Methods*, ANCOLD Bulletin No. 121, August 2002]. The event tree has these steps:

1. annual probability of highest reservoir level – estimates the annual probability that the highest level is within defined level ranges;
2. given 1, the conditional probability of initiation of erosion – the probability of a concentrated leak that starts the internal erosion process depends on factors such as presence of conduits, whether dam is or is not first filling and the water level;
3. given 1 and 2, the conditional probability that erosion continues – this probability depends on the presence or absence of intercepting filters and their compliance with design criteria;
4. given 1, 2 and 3, the conditional probability of a "pipe" developing – this depends on such factors as the rate of soil erosion, the compacted density of the soil, the moisture content of the soil at compaction, the inherent erodibility of the soil and whether the soil is saturated or not;
5. given 1, 2, 3 and 4, the probability that the "pipe" will result in a breach – this depends mainly on the zoning of the dam and the drainage capacity of the zones; and
6. at the appropriate place, the conditional probability of a successful intervention – this depends on such factors as the monitoring system, presence or absence of dam caretaker, rate of erosion progression, availability of materials and equipment to slow the erosion, accessibility of the dam, drawdown capacity of the dam.

Emeritus Professor Fell is currently working with the United States Bureau of Reclamation and the United States Army Corps of Engineers to further develop this method for estimating the probability of dam failure due to piping.

3. PROBABILITY OF SLIDING DUE TO FLOOD LOADING OF A CONCRETE GRAVITY DAM

The most likely failure mode for concrete gravity dams is sliding under flood load, particularly if the estimated magnitude of floods has increased since the dam was designed. This is a problem that lends itself to Monte Carlo simulation, linked to a conventional dam stability analysis program, as the means of estimating the conditional probability of dam failure, given a particular reservoir water level state. Such an analysis was undertaken for Hume Dam [McDonald, L A, Cooper B and Wan, C F, *Some Lessons from Use of Risk Assessment to Aid Dam Safety Evaluation*, Q76-R18, 20th Congress of the International Commission on Large Dams, Beijing, China, 19-22 September 2000]. For Hume Dam, all load and capacity input parameters, except for uplift pressure, were described by probability density functions. Uplift pressures were based on measured values. Such analyses are very revealing. For example, they showed that for a load [water level] that produced a computed *sliding stability factor* of 1.0 using conventional analysis with lower bound capacity and upper bound loads, the probability of the load exceeding capacity was surprisingly low. Account needs to be taken of the fact that some combinations of input values may have been demonstrated to be implausible by the survival of the dam under the historic high load. But consideration also needs to be given to the possibility that strength properties or the effectiveness of drains may have deteriorated since the historic high load occurred. An issue with such analyses is what to specify for the correlation between input parameters. For Hume Dam, all inputs were considered to be independent. It is possible to take account of correlation if there are sufficient data to estimate the correlations or if there is a reasonable basis for judging the correlations. With or without correlation, Monte Carlo simulation is a great aid to engineering judgment and considerably improves the understanding of the analysts.

4. PROBABILITY OF OVERTOPPING BY FLOOD

The procedures and guidance provided in Book VI of Australian Rainfall and Runoff were developed specifically with the objective of providing probabilistic estimates of flood loading, as is required for risk analysis. A number of developments have occurred since publication of the 1999 guidelines and these are being considered for inclusion in the current revision [update] being prepared for Australian Rainfall and Runoff. Monte-Carlo simulation is also well suited to the estimation of flood risk, and the characterisation of increasing uncertainty with flood magnitude can also be incorporated if the uncertainty of the estimates has an appreciable impact on safety decisions.

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