Dam safety: some economic regulatory questions, frameworks and directions

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

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Introduction

The Authority has requested Marsden Jacob Associates to review the Water Corporation's dam safety programme.[1]

Logic and premises

The Water Corporation's policy is to manage its dams in accord with ANCOLD Guidelines. In part, this reflects:

i) that tort and possibly criminal liability is a risk if a dam were to fail; and

ii) the fact that in the absence of specific legislation, the ANCOLD Guidelines set a community standard as does (best) practice in applying these Guidelines.

The Corporation is entitled to recover costs that are necessary and efficient under the current legislative framework. This recovery may be from customers or from Government.

However,

i) the Corporation is not entitled to recover costs which are inefficient, e.g., a) those that are gold-plated, inappropriately timed or do not represent best practice, and/or b) if a more competitive market structure would result in a lower level of effort and costs; and

ii) customers should not be obliged to pay costs which are unnecessary or due to discretionary decisions of the monopoly service provider.

Where costs are imposed on customers as a result of (or lack of) explicit government decisions to act, and this policy issue is under review, then these costs should be explicitly and separately identified.

Hierarchy of questions

The overarching regulatory question is '*Are the costs of the proposed dam safety programme necessary and efficient*?'

This raises several specific questions:

1. What flexibility is possible under the ANCOLD Guidelines?
2. Has the Corporation made full and efficient use of the available flexibility in the ANCOLD Guidelines to ensure that the costs and timing of expenditures on the south west dams are necessary and efficient?
3. How would the priority for safety expenditures on south west dams change if a wider portfolio were considered?

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[1] The Marsden Jacob team for this assignment comprised Dr John Marsden and Mr Len McDonald with assistance and advice from Drs David Bowles, Richard Davidson and Rory Nathan. The team acknowledges the assistance, cooperation and patience of the Corporation, particularly Michael Somerford and Sue Murphy.

Question 1: What flexibility is possible under the ANCOLD Guidelines?

The ANCOLD Guidelines comprise a family of documents based on engineering standards and risk assessment approaches. Of particular relevance are the ANCOLD *Guidelines on Risk Assessment* published in October 2003. These add to but do not supplant the remaining documents which are largely based on engineering standards.[2]

The engineering standards based documents offer little or no flexibility and are not further discussed here. There are therefore two basic and closely related questions: (i) *What is the applicability of the ANCOLD Risk Guidelines?* and (ii) *What is the flexibility permitted under the Risk Guidelines?*.

Question 1A: What is the Applicability of the ANCOLD Risk Guidelines?

The 2003 ANCOLD Risk Guidelines represent a major advance on the earlier 1994 Guidelines and in 2003 were seen as a challenge to the standards-based approach, and involved concepts which were not widely understood and were certainly not universally endorsed by dam safety engineers worldwide.[3]

> *At this time there remains a wide diversity of views within the engineering profession on many aspects of risk assessment for dams.*

The 2003 ANCOLD Risk Guidelines are modest in their claims. For instance the Foreword notes:

> *Risk Assessment gives us the tools to estimate the likelihood of a circumstance occurring and of its consequences. It also gives us tools to estimate what these will be after any improvement. These tools are diverse and can be imprecise and inconsistent. Len McDonald and his team have set about developing a set of guidelines to ensure that the best tools are selected, that they are used in the best way and that the results from different projects are consistent.*[4]

In addition, the improved tool offered was seen as work in progress:

> *As with other guidelines ANCOLD requests comments from the users of the guidelines and anticipates that they will need to be revised again as knowledge and experience in this area develops.*

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2 The ANCOLD flood guidelines and the earthquake guidelines allow for risk-based decisions – a fact many choose to forget.

3 Australian dam safety engineers had the opportunity to challenge the risk guidelines. There was a full day workshop at the ANCOLD/NZ conference in Auckland in November 2001 devoted to review of the draft by members.

4 Interpretation of ANCOLD Risk Guidelines: extracts from Australian National Committee on Large Dams Inc. (2003), *Guidelines on Risk Assessment*, October, the Foreword.

Moreover,

> *ANCOLD does not claim that risk assessment alone will provide sufficient guidance to decision makers. Rather it is one input in a difficult process.*

Thus the authors of the Guidelines saw the role of risk assessment as an enhancement to the traditional approach.

> *The risk-base approach should be used to extend the understanding gained from the traditional approach.*

The ANCOLD Risk Guidelines give explicit consideration to the relationship between the risk approach and the traditional standards approach. For instance, where the 'traditional standards' case requires an improvement but a 'risk approach' (RA) suggests more needs to be done, then the Guidelines recommend that the 'risk approach' be adopted. Piping risk is a typical example where the 'risk approach' may suggest a more demanding remedy than the 'standards-based approach' (SBA).[5]

The more interesting case is where *SBA is not satisfied, but RA indicates safety is adequate.* An example of this case is presented by the Logue Brook Dam (see Box 1). The ANCOLD Risk Guidelines' recommendation is as follows:

> *Where the SBA aspect is a widely accepted norm in the dams engineering profession in Australia, it should normally be met. Whilst it cannot be said that there would never be circumstances where the lesser safety level indicated by risk assessment is justified, a decision to not meet the SBA norm should be a rare exception, taken with great caution. The justification for not meeting the SBA requirement needs to be compelling and well documented.*

This paragraph is critical to the interpretation of the application of the ANCOLD Risk Guidelines. Persons favouring the traditional engineering approach emphasise the first two sentences, particularly the second sentence;[6] those favouring a risk approach emphasise the third and final sentence, which might be rephrased as *if you wish to depart from the comfort of traditional engineering standards then you need to make sure that the risk analysis is well done, transparent and very defensible.*

Thus, not only are the ANCOLD Risk Guidelines not prescriptive, but they permit both a standards-based approach and a risk assessment approach to be adopted. They therefore permit a range of interpretations, all of which can be accurately described as "*consistent with ANCOLD*". This range of interpretations is demonstrated by the different stances (outlined below) in Queensland, New South Wales, Victoria and Western Australia on the question of how dam safety remedies are justified.

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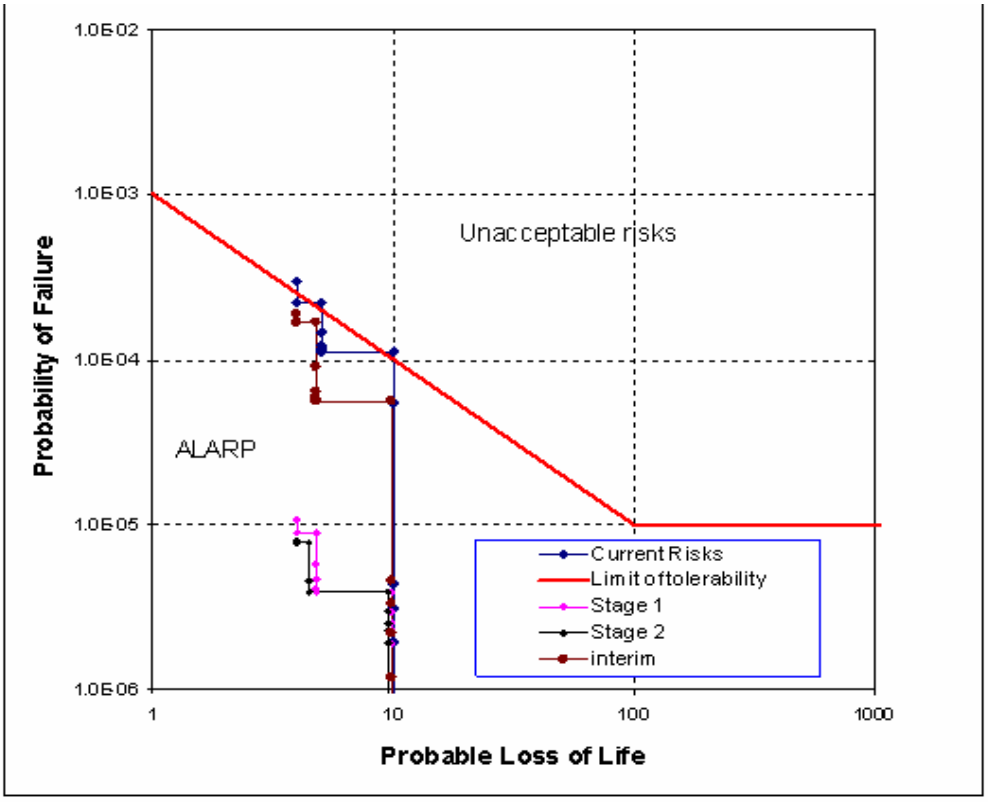
5 It can reasonably be claimed that no standard has been developed for piping safety of old dams.

6 A key issue here is that the flood guidelines [March 2000], particularly the fall-back table [Table 8.1], which the Corporation now sees as 'the standard', states that *"A deterministic fall-back option can be considered as an alternative to a risk study, preferably during a phased risk assessment that has identified the critical issues"*.

Box 1: Logue Case Study

The Logue Brook Dam provides an example where the justified level of safety improvements under a 'standards-based' approach is considerably in excess of the justified level under the ALARP principles of risk assessment.

Logue Brook Dam Risk Measured Against ANCOLD Societal Risk Guideline



The risk reduction from implementing the Stage 1 works is shown in the figure. Although this option produces a significant reduction in risk it does not meet current dam engineering standards. The ANCOLD risk assessment guidelines (ANCOLD 2003) are interpreted by the Corporation as not supporting the use of risk assessment to justify upgrades to less than the full standards upgrade.

The Corporation notes that the Stage 2 works will achieve compliance with standards but, as can be seen from the figure provides little improvement in the overall reduction of the risks posed by the dam. The Stage 1 works provide a solution that deals with the risk and is compatible with a future stage to upgrade to standards. However, the cost of safety improvements rises disproportionately with each stage. The Stage 2 works achieve a very small reduction in risk at a significant absolute cost and a 'cost of saving a statistical life' (CSSL) being in excess of $50 billion.

Queensland

The Queensland regulator of dam safety (located within the Department of Natural Resources and Water) issued, in February 2007, Guidelines which state that risk assessment should be used to justify the acceptable flood capacity for large dams. The particular Guidelines *relate to the flood safety of water dams, and more specifically, to the selection of an Acceptable Flood Capacity (AFC) and adequate spillway provisions for all proposed and existing referable dams in Queensland.*[7]

Guidelines on acceptable flood capacity have been actively considered by the Queensland Government since 2004. Stung by an estimate of $880 million to bring the spillways of the major dams in Queensland into conformity with the engineering design standards recommended by ANCOLD, the Queensland Government began a process to review the relevance and appropriateness of the recommended design standards. Part of this review included an expert report from Mr D. J. Blackmore. The resulting Guidelines on Acceptable Flood Capacity for Dams were approved by Cabinet.

The Guidelines present three methods for assessing Acceptable Flood Capacities: a small dams standard; a Fall-back option; and Risk assessment procedure (incorporating ALARP).

The option of falling back to design standards to determine the Acceptable Flood Capacity is intended "*where the cost of undertaking a full risk assessment is not warranted when weighed against the potential benefits.*"[8]

Since the costs of bringing spillways and flood capacities to engineering design standards are typically a multiple of the cost of bringing them to an ALARP based risk determined level of safety, the potential benefits of undertaking a risk assessment are for an existing dam likely to be very substantial compared with the cost of undertaking that assessment. As a result, it seems unlikely that the fallback option has a high relevance for existing dams.

On the risk based approach, the Queensland Guidelines comment on the advantages as follows:

> *In terms of safety, the traditional engineering approach has always been to specify the required flood discharge capacity for the dam at the design stage based on the relevant hydrological data and flood estimating and flood routing procedures. Hydrologic safety was considered separately from other risks, which resulted in identification of inadequate spillway capacity as a major cause of dam failure.*
>
> *More recent risk based approaches, such as that put forward by ANCOLD (ANCOLD 2003), indicate that hydrological safety should be assessed within the total load context in order to identify the priority of dam safety inadequacies and dam failure scenarios. Dam failure scenarios may include (but are not limited to) piping at dam headwaters elevated by flood, spillway malfunction or severe scour at lesser floods than extreme.*

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

[8] Queensland Department of Natural Resources & Water (2007) *Guidelines on Acceptable Flood Capacity*, February, p.1.

> *The risk assessment procedure is based on the ANCOLD risk assessment process and is consistent with the framework of the national standard AS/NZS 4360:2004 Risk Management. It is a comprehensive tool intended to enable the dam owner to evaluate the deficiencies and available risk reduction options.* ***This type of assessment should be adopted for major dams***.[bolding added]

Moreover,

> *The risk assessment procedure provides the owner with a review of the adequacy of the dam under all load conditions and failure scenarios, not just flood loadings. It also has the capability to more realistically assess the Acceptable Flood Capacity of gated spillway operations and the likelihood of premature failure due to causes such as spillway erosion.*

In summary, the Queensland approach endorses the risk-based approach for justification of dam safety upgrades to achieve acceptable flood capacity. In terms of prioritisation across the portfolio of risks and potential upgrades, as with the other States, portfolio risk assessment is employed.

New South Wales

The NSW Cabinet approved in August 2006, a *Risk Management Policy Framework for Dam Safety*.[9] Prepared by the Dam Safety Committee (DSC), the new guidelines emphasise the need for progressive improvement to ensure that each increment of safety expenditure provides the largest possible reduction in loss of life.

In terms of the justification of the level of safety adopted, the guidelines adopt as the default, the conservative end of the ANCOLD fall back table for flood capacity as the starting point for justification but allow dam owners/operators to make the case for a risk-based justification. This 'default plus option approach' means that the DSC can reject a risk-based justification if they do not feel that it is soundly based. Risk and standards-based approaches therefore coexist in the NSW framework as allowable methods for justifying safety levels.

In terms of prioritisation the NSW approach seeks to ensure the maximum gain in safety at all times through progressive improvement based on risk assessment.

[9] New South Wales Government (200) *Risk Management Policy Framework for Dam Safety*, Attachment 2 (extracted from Section 9 of Attachment 3) June.

Victoria

All Victorian water authorities are subject to a Statement of Obligations (SOO) issued by the Minister (see Box 2). Effectively, the SOO is a broadly expressed set of licence conditions. For the 17 authorities owning major dams, the SOOs contain essentially identical provisions relating to dam safety differing only slightly in the details of the reporting arrangements.[10]

The obligations and guidance contained in the clauses of Section 15 of the SOOs are high level and emphasise the need to consider all options and to reduce risk across the portfolio. Clause 15.1 states:

> *15.1 The Authority must develop and implement processes to identify, assess, manage, prioritise improvements to, and periodically review the safety of, dams operated by the Authority.*[11]

There is no explicit mention of how the final level of safety is to be justified. The relevant clause (Clause 15.2) states:

> *15.2 In developing processes under sub-clause 15.1, the Authority must have regard to the ANCOLD Guidelines and have particular regard to:*
>
> *(a) prioritising risks posed by the Authority's dams over all dams, components of dams and the types of failure; and*
>
> *(b) giving priority to reducing risks to life above other risks; and*
>
> *(c) basing the urgency of reducing the risk posed by a dam on the relativity of risks to the tolerability limits as defined in the ANCOLD Guidelines; and*
>
> *(d) basing programs for reducing risk on the concept "As Low As Reasonably Practicable" as defined in the ANCOLD Guidelines; and*
>
> *(e) where feasible, progressively implementing risk reduction measures to achieve the best outcomes for the available resources.*

This clause is ambiguous. Clause 15.2(d) can be interpreted as strongly endorsing a risk-based approach to justification. On the other hand, the opening sentence refers to ANCOLD Guidelines generically which allows an engineering standards-based approach to continue.

In contrast to Queensland and New South Wales, the Victorian regulator does not appear to issue major guideline documents.

In summary, while the Victorian approach strongly suggests a risk-based approach to justification, both the risk and standards-based approaches appear to be encompassed on a broader reading.

Thus, there appears to be some ambiguity in Victoria about the ability to also use a standards-based approach.[12] Prioritisation and progressive improvement is clearly risk based. A portfolio risk-based approach (PFRA) has been adopted in relation to dam safety

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[10] The 17 authorities include Melbourne Water, Goulburn-Murray Water (G-MW), Southern Rural Water and 14 regional urban water authorities.

[11] Melbourne Water Corporation, Statement of Obligations, Water Industry Act 1994.

[12] See Marsden Jacob Associates (2007b) for a discussion of the interpretation of the Victorian approach to justification of dam safety upgrades.

expenditure, with the use of PFRA mandated by the Victorian Government to assess the business risks of dams in that State.[13]

Box 2 : Victorian Statement of Obligations on Owners of Major Dams

15.1 The Authority must develop and implement processes to identify, assess, manage, prioritise improvements to, and periodically review the safety of, dams operated by the Authority.[14]

15.2 In developing processes under sub-clause 15.1, the Authority must have regard to the ANCOLD Guidelines and have particular regard to:

(a) prioritising risks posed by the Authority's dams over all dams, components of dams and the types of failure; and

(b) giving priority to reducing risks to life above other risks; and

(c) basing the urgency of reducing the risk posed by a dam on the relativity of risks to the tolerability limits as defined in the ANCOLD Guidelines; and

(d) basing programs for reducing risk on the concept "As Low As Reasonably Practicable" as defined in the ANCOLD Guidelines; and

(e) where feasible, progressively implementing risk reduction measures to achieve the best outcomes for the available resources.

15.3 The Authority must develop and implement a dam safety monitoring and surveillance program for each dam operated by the Authority, consistent with the ANCOLD Guidelines.

15.4 The Authority must develop and maintain a comprehensive database of all relevant dam safety information.

15.5 The Authority must prepare and give to the Secretary by 30 June each year a report that contains:

(a) a prioritised list of proposed dam safety works identified under clause 15.1 and the dates by which the Authority proposes to complete each of those works; and

(b) summary information:

(i) of the risk profile of each dam operated by the Authority, at the date of the report; and of each dam on which the Authority proposes to undertake safety works, after those works are complete; or

(ii) for each dam as agreed to by the Secretary; and

(c) a summary of the overall risk reduction profile of the Authority's dams or such other information as agreed to by the Secretary.

15.6 If for any reason the Authority is unable to undertake any proposed dam safety works identified under sub-clause 15.1 within the time advised, it must promptly prepare and give to the Minister a report which explains why the Authority is unable to undertake those works and includes any other information requested by the Secretary.

Source: Statement of Obligations issued by the Minister the Hon. John Thwaites for Melbourne Water Corporation.

[13] Dams Safety Committee (June 2006), *Review of Regulatory Policy Framework For Dam Safety*.

[14] Melbourne Water Corporation, Statement of Obligations, Water Industry Act 1994.

Tasmania

In Tasmania, the Water Management Act 1999 establishes the Assessment Committee for Dam Construction, operating under the Minister for Primary Industries and Water, as a decision-making body on the appropriateness of expenditure.

The Minister produces regulations on dam safety, which are largely based on ANCOLD Guidelines, but allow for variation away from the Guidelines.

Western Australia

The Western Australian model for dam safety policy setting is a self-regulatory model with the key policy decisions made by the Water Corporation. In contrast to the other three states, there is no explicit mechanism or recent example of consideration of dam safety policy by the Western Australian Minister or Cabinet. In contrast to the other four states, WA has no regulator of dam safety.

During the process of this review the Corporation stated that "*Water Corporation policy is to meet contemporary design standards. Risk assessment has not been used to justify a lesser standard.*"[15, 16]

Risk assessment is used to prioritise the sequence of safety upgrades.

Overview across jurisdictions

Table 1 summarises the similarities and differences in the way dam safety is justified across four states. In Queensland, the risk approach is effectively the sole basis for safety justification for existing major dams. This may also be the case in Victoria although the interpretation of the Clause 15.2 allows ambiguity. NSW allows both approaches.[17] Only in WA is the risk approach rejected as the basis for justification. All four states use risk assessment as the basis for setting priorities. Only in WA is there no explicit regulator of dam safety and no recent Government consideration of levels of dam safety.

[15] Water Corporation submission to ERA.

[16] This second sentence is essentially a paraphrase of the critical ANCOLD paragraph cited above and commencing *"Where the SBA is a widely accepted norm….."*.

[17] Given the outcomes to date on a practical basis Victoria would probably rank above NSW in using a risk-based approach.

Table 1: Basis of justification and prioritisation of dam safety upgrades – 4 Australian States, March 2007

	Explicit Safety Regulator	Basis of Justification		Prioritisation by risk
		Risk	Standards	
Queensland	●	●	–	●
New South Wales	●	◓	◓	●
Victoria	●	◓	◓	●
Western Australia	–	–	●	●

In the United States, the Bureau of Reclamation relies mainly on risk assessment to justify safety levels. An example of the reliance on risk assessment and the setting aside of traditional engineering standards is provided by the Ridges Basin dam where the Bureau decided on the basis of risk analysis to build a dam without a spillway, an option that would not be permitted under the traditional standards approach.[18]

Over the past two years, the US Army Corps of Engineers (USACE) has implemented a risk-based prioritisation and justification process for their dam safety projects. However, the criteria that are used for the design of the identified modification projects continues to be standards based. They are currently evaluating the implications of considering risk in the development of design criteria for dam safety modifications.[19]

The magnitude of the practical differences between using risk and standards-based approaches hinges critically on how quickly a safety program is implemented. As one industry professional noted:

> *In practice many hope that there is little practical significance between* [risk-based justification and the traditional standards approach] *as the safety management of a dams portfolio is an ongoing activity and if upgrades proceed in a staged manner then the final steps required to take an individual dam to a standards-based fix may continually be deferred for higher priority problems.*

In the case of the Water Corporation there has been a strong intent to proceed as rapidly as possible with the safety upgrades. For instance, in the case of the south west dams it was originally proposed that the program be completed over a five or eight year period. This contrasts with the intent of, say, G-MW to upgrade progressively their portfolio of dams over a 15 or 20 year period. This focus on progressive improvement over an extended period is not unique to dam owners supplying irrigation. For instance, the manager of a large portfolio of dams serving one of the major eastern state capitals commented *"my job is to shepherd our portfolio of dams slowly towards the gate (the ultimate objective); to keep the flock continually moving and to make sure there are no stragglers."* Similarly, the major Wivenhoe Dam, upstream of Brisbane with a population at risk in excess of 100,000, has been upgraded to deal with a flood capacity for an annual exceedance probability (AEP) of

[18] Cyganiewicz, J., (2006) *"Design and Construction of Ridges Basin Dam"*, paper presented to 2006 ANCOLD Conference, Manly.

[19] *Pers. Comm.* David Schaaf and Jeffrey Schaffer, United States Army Corps of Engineers, 14 March 2007.

1 in 100,000. This is a substantial upgrading in terms of the reduction in risk achieved but there is no short or medium-term timetable for further upgrades.

The Queensland guidelines for flood capacity indicate that the final stage of improvement to bring the required flood capacity is to be achieved in a little less than 30 years, subject to review when the full scale of the total Queensland program is known. The NSW risk management framework indicates that safety improvements are to be made as soon as reasonably practicable but generally within 10 years to bring risks down to the limit of tolerability and within 20 years for the ultimate stage.

Directions

The requirements of best practice governance of dam safety are now reasonably well understood (Box 3). To date, Western Australia has adopted a self-regulatory model for expenditures on dam safety. This model contrasts with the explicit regulator model adopted in other states.

Mandating a risk-based approach to dam safety in Western Australia would require :

- that the Government instruct the Corporation and other owners of major dams via its general powers under the Water Services Licensing Act (Section 18) or the Rights in Water and Irrigation Act (Section 27.B or Schedule 1, Division 2, Clause 7) setting licence conditions on the harvesting or taking of water; or
- that the Government provide a specific heads of power for dam safety through either a specific part of the general water legislation (as per Queensland) or a specific Act on dam safety (as per New South Wales); or
- that the Government establish a whole-of-government risk safety regulator and framework.

The current overhaul of the State's water legislation provides a partial opportunity to review how (and their relative benefits) the first two broad options above might be implemented.

The current review of Western Australia's water legislation provides an immediate opportunity to consider and determine the choice between different options for mandating a risk-based approach. However, consideration of legislative reform to establish a State-wide whole-of-government office of safety or equivalent would require a broader forum.

Box 3: Essential Elements of a Dam Safety Regulatory Scheme

[Drawn from Bradlow, D D, Palmieri, A and Salman, S M A, *Regulatory Frameworks for Dam Safety: A Comparative Study*, Law, Justice and Development Series, The World Bank, Washington DC, 2002 – pp. 72 -85]

The Form of the Regulation

The regulatory framework should be clearly spelled out in publicly available documents. Legal instruments vary from country to country. The variations can be summarised as follows:

- There is often more than one instrument;
- The first instrument is a statute or law. The statute should not be easily changed, should be simple and should contain only the objectives and general principles governing the regulatory framework;
- The statute should clearly stipulate the responsibilities of all parties involved with dams, the identity of the regulatory authority and the authority responsible for emergency response;
- The details of the regulatory scheme should be in regulations or decrees that are relatively easy to change;
- The regulations may be supplemented by non-binding guidelines.

The Institutional Arrangements

Matters to address are:

- The powers and responsibilities of the regulatory authority should be spelled out;
- The authority must be independent of all those who make decisions about whether to build dams and all those involved in operation and maintenance of dams;
- The authority must be provided with adequate human and financial resources to perform its functions.

The Powers of the Regulating Entity

Powers should include:

- The power to identify and develop norms, standards and guidelines dealing with dam safety;
- A voice in decisions to issue permits or licences for construction and operation of dams;
- The power to monitor inspections conducted by others and to reject the findings;
- The power to conduct its [the regulatory authority] own inspections;
- The power to approve the party selected by the owner or operator to undertake inspections;
- The responsibility to maintain a register of dams within the jurisdiction;
- The responsibility to advise owners and other interested parties about dam safety issues and developments in the regulatory framework;
- The responsibility to make publicly available reports on dam safety issues to government and to advise government on such issues;
- The power to enforce the regulatory framework.

The Content of the Regulatory Scheme

The regulatory scheme should include:

- Clear criteria for determining which dams are regulated;
- Definition of the scope of the scheme – it should address dam safety issues at all stages of the dam life cycle;
- Clarification that it is the owner that has the primary responsibility for dam safety and which can be held liable for damages;
- Stipulation of the dam safety standards with which the owner is to comply;
- Establishment of the qualifications of persons undertaking safety evaluations for the owner;
- Stipulation that the owner or operator must make periodic reports to the regulator on the results of monitoring, inspections and reviews;
- Stipulation of the frequency with which the owner or operator is to conduct dam safety inspections and reviews;
- Stipulation that the owner or operator must maintain complete records on the dam;
- Requirement of all dams to have an operation, maintenance and supervision manual and an adequate budget for operation, maintenance and supervision;
- Imposition of [any] fees that dam owners or operators must pay to the regulatory authority;
- Requirement of dams with the greatest hazard potential to have an emergency plan that is provided to the regulatory authority and to all other authorities and downstream communities that could be affected by a dam failure. The regulatory authority should provide dam owners with guidance on the issues to be addressed in the emergency plan.

In terms of **justification** of dam safety levels, the Corporation has, as noted, made decisions consistent with ANCOLD Guidelines but has not utilised the flexibility provided by risk assessment in the manner that occurs in other parts of Australia. Particularly in expenditures relating to spillways and flood capacity this suggests that the Corporation's actual and proposed expenditures on safety improvements will be higher than necessary and therefore would not be considered efficient. The comparative costing information necessary to estimate how much higher than necessary is not shown in the Corporation's investigation reports or design reviews. However, the information on 'cost to save a statistical life', provided by the Corporation, suggests the effect could be substantial, *prima facie.*

On the question of progressive upgrades of individual dams, MJA's review of the investigation and design reports and other documents provided by the Corporation on the south west dams indicated extensive considerations of different options for moving to a fully fix result but generally much lesser consideration of staged options. Nonetheless, the more recent assessments do explicitly explore staging and recognise that the diminishing returns to later stages.

In response to questions to the Corporation on these questions, additional information provided to the MJA team indicated that staging was not always practical or economic for these particular dams.

Logue and Waroona are different cases however (on Logue, See Box 1 above).

In the case of Waroona Dam, the potential staging was abandoned primarily on the basis that the (present value) cost of the Waroona upgrades program would be lowered overall. But this was because there was a relatively short interval between stages, a fact that also caused local objection to staging. However, minimising the present value cost may not be the relevant yardstick. In particular, if the policy objective is to ensure that at each stage and each increment of expenditure, safety is improved to the maximum extent, then prioritisation and sequencing may differ from the sequencing consistent with simply minimising the cost of the upgrades for a particular dam.[20]

In terms of **phasing and timing** of remedial actions, the Corporation has indeed used a PFRA approach to prioritise its dam safety program, and this program and its component elements are then subject to the discipline of the wider capital budgeting process.

However, since the Corporation has relied on risk assessment for the purposes of prioritisation only, the investment in the formulation of judgements and estimates of probabilities, population at risk can be expected to be at a lower level than dam owners preparing risk assessments in order to justify safety levels. This follows because the ANCOLD Risk Guidelines and the state regulators insist that the risk assessments for this more demanding purpose must be transparent, defensible and compelling.

In terms of timing, decisions to amalgamate different parts of a safety upgrade for a particular dam into a single fix appear to have been based on minimising the cost of the program, rather than maximising the progressive improvement in safety levels across the entire portfolio.

[20] The latter depends on minimising the present values, whereas the former depends on minimising the present value of the cost of saving a statistical life.

In terms of the **ability to widen the portfolio** to cover all risks facing the Corporation, the Corporation's capital budgeting process provides scope to achieve this objective (no submission has yet been received from the Corporation on the capital budgeting process).

Question 2: Has the WC made full and efficient use of the available flexibility in the ANCOLD Guidelines to ensure that the costs and timing of expenditures on the south west dams are necessary and efficient?

To address this question requires an explicit framework against which to assess the Corporation's actual and proposed expenditures. We consider first the elements of this framework.

Elements of a framework for assessing the necessity and efficiency of dam safety expenditures

Based on MJA's detailed review of the flexibilities permitted under the ANCOLD Risk Guidelines plus the review of practice relating to the justification of safety upgrades, the following framework was employed for the assessment of whether the Corporation's expenditures on the south west dam safety upgrade program are necessary and efficient.

The cornerstones of this assessment framework include the:

i) justification of dam safety levels by risk analysis which is transparent, defensible and compelling. Under this framework, director protection is afforded by risk assessment based on the ALARP principle with its factors of disproportionality since these factors of disproportionality are explicitly based on tort case law. Provided UK case law provides adequate guidance in the Australian situation, director protection does not require use of traditional engineering standards, although directors personally may take greater comfort where these apply.[21] Where director protection afforded by the use of traditional engineering standards involves substantially higher costs, that additional level of protection beyond the ALARP level should be considered excessive, unnecessary and inefficient;

ii) phasing and timing of remedial actions. This is consistent with the Portfolio Risk Assessment Approach (PFRA) and is mandated by dam safety regulators and/or their Ministers in NSW, Victoria and Queensland;

iii) potential to widen the portfolio of risks to cover all risks facing the dam owner. Clearly risks (such as Occupational Health and Safety) involving criminal liabilities rank above risks potentially involving civil liabilities such as dam safety. ANCOLD is silent on the treatment of other risks faced by the organisation, but legislation is not. Any organisation clearly has a responsibility to deal with other risks, some of which will rank ahead of dam safety.

[21] Recognised good practice is a factor in demonstrating ALARP under the HSE system – it is a base below which safety should not fall. However, the ANCOLD fall back flood capacity does not constitute good practice in the HSE sense because the guidelines explicitly say that the fall back is conservative [safer] and an alternative to a risk-based flood capacity.

In the absence of legal advice to the contrary, at a minimum, the prioritisation and sequencing of safety upgrades should cover the entity's entire portfolio of risks That is, prioritisation of safety upgrades using PFRA approaches should be endorsed for both the portfolio of dam safety risks and the wider portfolio of risks facing the dam owner. An expanded portfolio risk assessment approach (EPRA) should be adopted; and

iv) ability to widen the portfolio of risks to cover all risks facing Government. This is obviously sensible from a community perspective but directors may be exposed unless specific protections are provided or legislation is changed. Until these whole of government actions are taken, an expanded portfolio risk assessment (EPRA) approach cannot be readily applied. This element therefore is not relevant to the assessment of the Corporation's past expenditures on dam safety but ought to be relevant to proposed future expenditures.

Question 3: How would the priority for safety expenditures on south west dams change if a wider portfolio were considered?

The necessity for expenditures for safety upgrades of the south west dams and the efficiency in the sequencing and timing of these expenditures are potentially affected by several mechanisms. These are:

i) the adoption (in place of traditional engineering standards) of a risk assessment based on the ALARP principle to set the justification of safety levels. This would likely eliminate substantial expenditures. As noted, the precise degree to which this would occur is, however, judgemental because the Corporation and its consultants, as a matter of policy, did not consider an ALARP-based risk justification in the detailed investigation reports and design reviews;

ii) an approach to staging more in line with Queensland, Victoria and New South Wales – that is, substantial deferment of fixes below the limit of tolerability;

iii) the use of an expanded portfolio risk approach (EPRA) across the Corporation's risks. This may extend the timing to complete the program (which would have been reduced by the adoption of risk-based justification) as per Item (i) above; and

iv) the use of an EPRA across the wider portfolio of risks facing the Western Australian community.

These four mechanisms operate to reduce the magnitude of expenditure on the safety upgrades of the south west dams which can be considered to be necessary and efficient. As each mechanism becomes relevant, layers of costs are removed or are deferred in favour of more effective safety improvements elsewhere so that the present value of the costs is further reduced.

Table 2 shows the notional change in costs as these mechanisms are applied to derive the quantum of necessary and efficient costs in present value terms.

To indicate the magnitude of the changes that would result requires information on:

- (as noted) the comparative expenditures required for a risk approach vs standards;
- options and opportunities for phasing of dam safety upgrades;
- the wider portfolio of risks within the Corporation;
- the wider portfolio of risks from government owned infrastructure and services in WA; and
- the wider portfolio of all risks facing the WA community and opportunities to reduce them.

Table 2: Notional apportionment of costs and cost recovery in accord with premises outlined

	Comment
Total cost of program proposed	South west dams only, all costs expressed in present values to reflect timing differences.
Less extra costs due to use of standards-based approach rather than ALARP to protect directors	The potential difference in the nominal costs of a 'standards' versus 'risk' based fix is large. However, the potentially very large difference between the cost of 'going to standards' and the costs of a risk-based justification is small in present value terms due to the priority given to doing the more cost effective options first
Less costs reduced by explicit phasing and staging in a similar manner to Qld, NSW and Victoria.	
Less south west dam safety costs deferred as a result of explicit prioritisation within the Corporation.	The magnitude of these costs may be small since the Corporation is scrutinising the dam safety program as part of its capital budgeting process.
Necessary amount that WC is entitled to recover	
Less costs deferrable by WC if new State legislation enacted to prioritise safety expenditures across a whole-of-state portfolio of risks	This reduction is due entirely to the deferral of high cost safety upgrades for dams as a result of giving priority to the more cost effective opportunities to reduce the higher risks of life loss, injury and economic impacts facing the WA community. This cost can be viewed as customer financed CSO payment compensating the WC for the Government's default decision to date not to enact appropriate legislation
Necessary and efficient amount payable by water customers under recommended arrangements.	

Much of this information is not readily available to the Authority or its consultants, however, a broad indication can be provided by examining the impact on the Corporation's dam safety program of different threshold levels for the 'cost of saving a statistical life' (CSSL). Such thresholds are relevant in several ways: first because the ALARP test, with one important consideration being the factors of disportionality, is the determinant of the risk-based justification **once** risks have been reduced to the limit of tolerability; and, second, the CSSL is a useful measure (but not the sole factor) when considering the priority and sequencing of portfolio of safety improvements.

Table 3 (which is repeated from the main paper) shows the notional change which can be expected when different thresholds are applied. It shows not only how amounts spent on the Corporation's dam safety program would change, but that more money would be potentially available to deal with life safety risks affecting other utilities, road safety, hospitals and other areas of community risk. Importantly, it also recognises that the deferral and delay of dam safety expenditures to some future date could have a substantial impact on the present value of the costs to be shared with Harvey Water. (Note that the purpose of Table 3 is purely to show the logic; the numbers inserted are purely indicative.)

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)	Residual of all 90 dams		($ million)	
Current legislation	150	100		250	102
New legislation and with threshold of:					
$1 million/SLS	50	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.

We have therefore reviewed the Corporations' November 2006 portfolio risk assessment which provides estimates of the population at risk (PAR), failure probabilities, probable loss of life (PLL) and derives estimates of the CSSL. Some adjustments were made by MJA to take account of the most recent information. The Water Corporation may not fully agree with our figures but any differences are now minor in our judgment.

Table 4 shows the impact on the Corporation's proposed dam safety program in total and for the south west dams on applying the ALARP justification thresholds tentatively recommended by the ANCOLD Risk Guidelines for existing dams.

Table 4: ANCOLD's tentative guidance on ALARP thresholds and justification

ALARP Threshold	Justification Rating	Proposed Capital Expenditure			
		Total Program	South west Dams only	Present Values	Based on Assumed Deferral
CSSL ($/million)		$/million	$/million	$/million	Years
0 – 5	Very strong	15.5	.001		
5 – 20	Strong	117.7	12	8.6	5
20 – 100	Moderate	82.6	-	-	10
100 plus	Poor	120.0	67.3	8.8	15

Source: ANCOLD (2003), Guidelines on Risk Assessment, p.125 and Marsden Jacob Associates analysis based on the Water Corporation's PFRA spreadsheet dated November 2006.

The final two columns of Table 4 provide an indication of how the deferral of those expenditures which are less effective in saving lives in favour of those which are more effective reduces the present values of the costs for the south west dams. Giving higher priority to expenditures which save lives very effectively over those expenditures which are

much less effective allows more lives to be saved. It also has the effect of reducing quite dramatically the present value cost of the bulk of the proposed program (which has poor justification only in terms of the CSSLs).

In terms of the ANCOLD tentative guidance on ALARP justification thresholds, virtually none of the south west dam program has a very strong justification. Of the $89 million program still remaining for the south west dams only $12 million would be classified as having a strong justification. The overwhelming part of the remaining program must be assessed as having a poor justification if the tentative guidance suggested by the ANCOLD Risk Guidelines were to be applied.

Moreover, the ANCOLD thresholds for ALARP justification can be viewed as extremely conservative. This occurs because they are based on an interpolation between the United Kingdom inferred threshold and that deduced from United States regulatory practice. If the value of a human life based on Australian estimates were applied and the HSE disproportionality factors were applied, then the $100 million threshold would be reduced to $30 million.[22]

Directions

High cost methods of affording director protection cannot be necessary and efficient where there are lower cost methods available which achieve the same outcomes. Consequently, the continued use of traditional engineering standards cannot be endorsed where, in compliance with the ANCOLD Risk Guidelines and observed practice in other states, a risk-based approach focussed on ALARP principles with factors of disportionality is available. This risk-based approach has been available since October 2003 when the ANCOLD Risk Guidelines were finally published. As a matter of principle, the difference in expenditures between an ALARP risk-based justification and an engineering standards approach should be disallowed as a recoverable cost.

It is an essential feature of the ANCOLD Risk Guidelines that risk be reduced to or below the limit of tolerability. All six dams were assessed by the Corporation as being above the limit of tolerability pre-improvement. The ALARP principles then apply to consider whether further safety improvements are required. It is quite possible that the cost of reaching the limit of tolerability involves high CSSLs. In terms of justification, the safety improvement is nonetheless still required since the obligation is to lower risk to the limit of tolerability. However, this does not mean that consideration of the CSSL (or other ALARP measures) is not relevant. Prioritisation across the wide portfolio of possible safety improvements (all of which may be above the limit of tolerability) is still required even if this needs to apply to a portfolio which is partitioned into those risks which are above the limit of tolerability and those which are at or below and subject to the ALARP principle.

In terms of prioritisation and sequencing, and in terms of ALARP justification, actions with low cost effectiveness should receive lower priority – unless the absolute level of risk is unacceptable. Rather than set an explicit cap or threshold of, say, $30 million in terms of the

[22] The value of saving a human life in Australia has been estimated to be around $2.5 million or $2.7 million if increased for inflation to 2006 prices. Applying the upper bound of the HSE recommended factor of disproportionality of 10 would suggest that the need to demonstrate disproportionate sacrifice would be satisfied where the cost of saving a statistical life is around $27 million or perhaps $30 million. See Attachment B.

CSSL, beyond which safety upgrades could be considered unwarranted or inefficient, a preferable approach is to establish a trigger and challenge process.

Under this challenge process, safety upgrades involving high costs for saving life or involving a poor benefit cost ratio would require more consideration of the reasons for justification including the (budgetary) impact on other risk reducing options.

In terms of the currently proposed program, the budgeted investment expenditure is now around $150 million.[23] This compares with approximately $89 million for the same schedule of works shown in the Corporation's PFRA spreadsheet of November 2006. This $89 million includes the $12 million expenditure already incurred in constructing the Harvey Dam and $21 million already spent for the Waroona upgrades.

For the purposes of setting the level of costs which should be shared with Harvey Water, MJA's analysis of the PFRA spreadsheet (reported above) has identified only $12 million or 14% of the full schedule of works for the south west dams as having better than a 'poor' justification in terms of the ANCOLD recommendations on tentative thresholds. This provides one dimension of guidance on the level of dam safety costs to be recognised as necessary and efficient.

The safety upgrades for the Waroona Dam were completed in 2003 and therefore pre-date the publication of the ANCOLD Risk Guidelines. Any issues with the necessity and efficiency of Waroona expenditures must therefore be independent of the use of a risk approach to justify the final level of safety upgrades. However, questions relating to the prioritisation and sequencing of the Waroona upgrades remain.

[23] Water Corporation advice to the Authority, dated 15 March.

Question 4: Assessment of the Corporation's approach to risk assessment for each of the south west dams

The priority for safety expenditures on south west dams would change if a wider portfolio were considered. This is demonstrated simply (and mechanically) by examining the impact of imposing different levels of threshold on the cost of saving a statistical life (CSSL). However, this demonstration is dependent on the Corporation's estimates of the probabilities of failure, pre and post safety improvement, the population at risk and other key parameters in the risk analyses that have been undertaken. The reliability of the analyses therefore presented in consideration of Question 3 above is therefore dependent on the reliability and relevance of the Corporation's risk assessments. We therefore examine this question below.

In terms of both justification and prioritisation of a remedial program of dam safety work based on risk assessment, the critical parameters are those relating to probability of dam failure, the probable loss of life (PLL) in the event of failure, and the cost of saving a statistical life (CSSL).

Examination of the Corporation's investigation reports and detailed design review indicates a well developed and documented understanding of the nature of the individual risks facing the dams and of the remedial options. Fine engineers and safe dams do not automatically imply a sensible use of the community's resources or sensible decisions about improving safety more generally. Other questions therefore need to be examined.

As noted, the Corporation has, as a matter of policy, not explored until recently risk assessment to any level that might challenge a standards-based justification. Nor has the Corporation always examined the level of safety upgrades which would satisfy the objective of protecting directors through the disproportionality factors in the ALARP criteria – again this is consistent with the Corporation's policy of rejecting a risk assessment approach in favour of the traditional engineering standards approach.

Since the Corporation has not placed ultimate reliance on the risk numbers it is essential that they be scrutinised if they were to form the basis for a risk-based approach. Such scrutiny should be in accord with the criteria and guidance established by ANCOLD.

On the essential purpose of risk assessment, the ANCOLD Risk Guidelines state:

> *The essential purpose of risk assessment is the explicit and transparent treatment of uncertainty. It is a systematic process, which extends and enhances the understandings obtained from the traditional engineering methods of dam safety assessment, and should be applied in conjunction with those traditional approaches. The aim is more informed decision-making.*

ANCOLD explicitly recognises the concern that risk assessment can be unstructured and of poor quality and the scepticism that "*risk assessment is just throwing darts*". ANCOLD therefore establishes explicit guidance on how to achieve the most robust, transparent, defensible and compelling outcomes that can be achieved, given current knowledge.[24]

> *To avoid a situation where judgement degenerates into poorly informed guessing, the following minimum precautions should be observed:*
>
> - *those making the judgements should have wide experience of dams engineering, and extensive knowledge of dam failure case histories, but there is a case for inclusion of generalists as well as relevant specialists;*
> - *there should be a mandatory requirement for more than one person making the judgements, and where values differ significantly there should be elicitation of the reasons, by a process of questioning, and then convergence by challenge and debate;*
> - *the logic of the failure process, usually defined by event or fault trees, should first be agreed by the experts and then the focus should be on estimating the probability density functions for the outcomes on each branch;*
> - *the reasoning that supports the judged values should be clearly documented;*
> - *there should be independent review of the reasoning behind the values. It is not acceptable, at any level of risk assessment, that a single individual be fully responsible for judged probability values.*[25]

This guidance including the five minimum precautions provides a framework against which to assess the Corporation's risk estimates. In addition, beyond the ANCOLD precautions there is a developed body of best practices in the conduct of risk assessments (see Boxes 4 and 5).

To undertake this assessment the MJA team of international dam safety experts reviewed a selection of core documents for several of the dams including particularly Waroona, Wellington and Logue Brook dams.

Specific questions explored for each dam include:

- have the safety issues been correctly identified? As noted, the answer to this question is strongly affirmative and it is not pursued further here;
- Is the population at risk a reasonable and statistically unbiased estimate?
- Is the basis of the stated probabilities for relevant events and consequences documented?

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[24] *Reliance on subjective judgement for estimation of probability is an inevitable element of risk analysis for dams, to a greater or lesser extent, but structured procedures need to be followed to ensure reasonable reliability of the estimates. Research indicates that the judgement of specialists of high reputation sometimes have poor reliability, but there is also evidence to show that the mean position of the judgements of a group of experienced people is superior to the judgement of an individual* (Jones, 1999). (Interpretation of ANCOLD Risk Guidelines: extracts from Australian National Committee on Large Dams Inc. (2003), Guidelines on Risk Assessment, October, p.71.)

[25] Interpretation of ANCOLD Risk Guidelines: extracts from Australian National Committee on Large Dams Inc. (2003), Guidelines on Risk Assessment, October, p.72.

- Do the probabilities of the event and of failure appear reasonable? Have conditional probabilities been recognised and handled in accord with best practice? Reflecting 1 and 2, are the estimated PLL values reasonable?
- How have the questions of justification and cost effectiveness been handled?

Approach

The MJA panel met with the Corporation's manager of dam safety at the November 2006 ANCOLD Conference and requested:

- the more recent portfolio assessment report (dated 2004);
- the most recent version of the PFRA spreadsheet (dated November 2006); and
- for each of the six dams, all relevant detailed investigations and design reviews.

The Corporation provided on 6 December 2006:

- a summary overview;
- the 2004 PRA report; and
- the November 2006 PRA report.

Copies of the investigation reports and design reviews for the individual dams were provided progressively during January and February 2007. Workshops with the Corporation were held in February and March.

As items of information have been received, analysis triggered further questions and therefore additional information was requested. In particular, following receipt and analysis of the Wellington reports, copies of the Graham spreadsheets calculating PLL were requested for Wellington and the other south west dams. A copy of the dam break analysis report and associated maps were also requested for Wellington.

Assessment of the Corporation's Dam Safety Programme

As may be expected, the Corporation's approach to justification and prioritisation has developed over time with increasing use of risk analysis and increasingly thorough risk analysis. The Corporation's statement that the quality of the probability analysis undertaken for Waroona is not indicative of current practice is quite correct. This was confirmed by detailed comparison of the risk assessments for Waroona with those for Samson Brook, Stirling, Logue Brook and Drakesbrook. Based on our initial review, attention was then directed particularly to the Corporation's risk assessments of Waroona and Wellington.

Issues relating to Waroona Dam

The safety upgrades for the Waroona Dam were completed in 2003 i.e., before the issue of the ANCOLD Risk Guidelines. With the Waroona Dam, particular scrutiny was directed to the PLL estimates and the methods by which these were derived. Issues tentatively identified with the Waroona PAR and PLL include:

i) number of occupied houses and population at risk [PAR] may be too high. There is a noticeable gap between the Corporation's estimates, which we understand were based on aerial photography and windscreen inspections, and the doorknock of the area undertaken by Harvey Water. The Harvey Water estimate lists every household by name and gives the number of persons therein. The Water Corporation gives number of dwellings by distance downstream of the dam but does not document the process followed to arrive at the numbers;

ii) resident PAR should vary according to time of day and day of week;

iii) flood severity based on peak depth and velocity on cross-section instead of those applying where the houses are – we believe medium/low boundary should be moved back from 10.0 km downstream toward 9.0 km downstream. This small change has a large impact on PLL. Flood event loading domain has not been partitioned;

iv) *high* flood severity based on depth of flood [>30m] instead of rapidity of increase in depth – should be *medium* in our opinion;

v) warning time parameters used in the analysis are not based on the actual warning and evacuation arrangements, rather, they are based on the default parameters provided in Graham (1999), Table 2;

vi) when estimating the PLL no allowance appears to have been made for houses on raised earth pads, a requirement via Council regulation due to water-logging in that area. This would reduce the height and severity of flood in the event of dam break and, therefore, PLL; and

vii) the reasoning behind and basis of the probability estimates is not stated and not documented.

Our understanding is that the Water Corporation rejects some of these points.

Main findings

The main findings are:

i) The Corporation's identification of dam safety risks and engineering options is of a highly professional order.

ii) The Corporation's decisions are consistent with its policy of compliance with ANCOLD Guidelines.

iii) To justify the level of safety upgrades, the ANCOLD Risk Guidelines permit the use of both traditional engineering standards approaches and risk-based assessments. In contrast to the policies of Queensland, Victoria, New South Wales and Tasmania (which either mandate risk-based justification or allow both approaches), the Corporation's policy is to rely on a traditional engineering standards-based approach for justification.

iv) Consistent with the ANCOLD risk guidelines and the practice mandated by governments in other states, the Corporation uses risk analysis to prioritise the sequencing of dams and potential upgrades.

v) Detailed inspection of the design review and investigation reports provided by the Corporation confirms that the quality of the risk analyses and assessments undertaken for or by the Corporation has increased very substantially since 2003 when the ANCOLD Risk Guidelines were issued. The quality of the Corporation's risk analyses is now of a high order. However, the quality of the earlier risk analysis for Waroona Dam and for Wellington Dam is less robust.

vi) There is a common concern for five of the six dams that estimates of the Population at Risk (PAR) may not be robust and may have been overestimated. The detail of the available documentation on the PAR estimates for four of the remaining dams is not sufficient to suggest that the issues noted for Waroona do not apply across the board. Prima facie, the issues raised by Harvey Water over the PAR estimates for Waroona Dam (where there are two widely divergent counts) appear to apply to all dams other than Wellington. Any changes to the PAR estimates would affect the estimated Probable Loss of Life (PLL) for each dam and therefore the priority of the upgrades and possibly the justification of the upgrades.

vii) In the case of the sixth dam, **Wellington Dam**, the new PAR estimate has been undertaken differently and appears to be reliable. In response to queries on the probabilities of failure and the dam break analysis, these and the severity of the flood that would result from a dam break have been explored with the Corporation by the Authority's consultants. The Corporation will further explore locational and timing variations in the severity of the flood and its impact on PLL and the potential for Monte Carlo analysis to better inform the probability analysis. These refinements may affect the priority which ought to be accorded safety improvements for Wellington Dam, but are not expected to affect the need to reduce the risk of failure to below the limit of tolerability.

viii) Subject only to the concerns over the PARs, the risk assessments for **Samson, Drakesbrook and Stirling** dams are of a generally high order.

ix) In the case of **Logue Brook** dam, the pre-improvement failure probabilities and PLL place the risks just above the limit of tolerability. With the interim improvement achieved by lowering the Mean Operating Level (MOL) to 1.5m below the existing spillway crest, the risk is now assessed by the Corporation to be below the limit of tolerability. Neither the proposed Stage One improvements nor the Stage Two improvements can be justified by the ALARP principle on the cost-effectiveness thresholds recommended in the ANCOLD Risk Guidelines. The CSSL estimated for Stages One and Two are, respectively, around $1 billion and greater than $50 billion. Unless other ALARP considerations intervene very heavily, neither Stage One nor Stage Two can be justified in terms of the CSSL.

x) In the case of **Waroona Dam**, the initial risk assessments were undertaken prior to 2000. Although the ANCOLD 2003 Risk Guidelines had not been published at the time of the decision in December 2001 to proceed with the upgrade to standards, the development of the Risk Guidelines reflects the experience of insights from those dam owners undertaking best practice risk assessments prior to that date.

Information available to the Authority's consultants on the Corporation's assessment of the risks indicates that the Stage One improvements would have alone shifted the risks associated with Waroona Dam, as assessed at that time, to below the limit of tolerability.

The estimated CSSL for Stage One and Stage Two combined is around $170 million per life. By inference, the CSSL for Stage Two would be higher, likely materially so. Stage Two would either not have been justified, or would certainly have been deferred. Stage Two would have been justified under the ANCOLD's engineering standards approach but could certainly have been deferred. Once the ANCOLD Risk Guidelines were formally published, Stage Two could not be justified unless other (and unknown) ALARP considerations intervene heavily. The conclusion that Stage Two is either not justified or should have been substantially deferred also follows quite separately from the application of the convention "as if they [Harvey Water] owned the dams" were applied.

Finally, these conclusions are further reinforced by the probable over-estimation of the PLL. The PAR estimates for Waroona have been reviewed and challenged by Harvey Water with credible alternative estimates based on an enumerated doorknock of the resident population. This much lower PAR estimate and several reasons why the severity of the flood resulting from a dam break would be lower, points to a much lower PLL.

The decision not to stage the Waroona improvements was based on several factors including the economies from undertaking the two stages together. A second important factor was the combination of the assumption that the gap between Stage One and Stage Two would be a short period only and the presumption that the objective is to minimise the present value of expenditures rather than to maximise the progressive improvement in life safety and in reduction of economic loss. For a discussion on the application of this, see MJA (2003).

Issues relating to Wellington Dam

Initial inspection of the Wellington Dam documents raised the following issues:

i) the population at risk (PAR) has been estimated by the same approach and method as Waroona. Might the same concerns with over-estimates apply? If not, why not? What explains the sharp jump in road user PAR around the by-pass road but not at the highway upstream?

ii) Is the conditional probability of dam failure, given the annual exceedance probability [AEP] flood, adequately explored?

iii) Is the flood height of 13 metres on the coast defensible or has the flood depth/velocity and flood severity resulting from the dam break been overestimated?

iv) How would a revised set of parameter estimates affect the PLL and, therefore, the magnitude of the CSSL?

In terms of the probability numbers relating to Wellington, the MJA team could not identify documented reasoning to support the probabilities. In addition, one failure mode may have been omitted with the over-topping failure mode not quantified in the probability of failure estimate. These and related questions were therefore addressed and workshopped with the Water Corporation.

Box 3: 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.

Box 4: Risk Analysis for Dams

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, the documentation is actually done progressively through the analysis.

Box 4: Risk Analysis for Dams (continued)

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 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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