The Australian National Committee on Large Dams ("ANCOLD") produced the Guidelines on Risk Assessment ("Guidelines") in October 2003. The possible roles for risk assessment in reaching a conclusion on the safety of dams were given in the Guidelines as:

(a) an enhancement to the traditional method;
(b) an alternative to the traditional approach; and
(c) a sole basis for decision making.

At the time of the Guideline publication, ANCOLD only supported the first of these roles for important and conclusive decision making regarding dam safety. However, current use of the guidelines and application of risk assessment techniques have evolved and some of the States within Australia have accepted the second of the above, i.e. the use of both the traditional and risk assessment techniques for the safety regulation of dams.

ANCOLD is currently in the process of developing supporting information for the Guidelines in order to:

1) Re-emphasise practice that is important but generally not being followed;
2) Provide explanatory notes to update practice or enhance guidance already provided; and
3) Introduce new concepts that should be included in current practice.

The purpose of this paper (and conference presentation) is to provide an overview of the practices being followed within the Australian States with regard to the application of risk assessment in dam safety management and to provide information as to the status of the ANCOLD Guidelines on Risk Assessment supporting information.

INTRODUCTION

The 1994 ANCOLD Guidelines on Risk Assessment set out the conceptual foundations of risk assessment, as understood at the time and the 2003 Guidelines were directed to the practical application of risk assessment, as an aid to better dam safety management.

The glossary definition of Risk Assessment given in the Guideline is:

Risk assessment - The process of deciding whether existing risks are tolerable and present risk control measures are adequate and if not, whether alternative risk control measures are justified or will be implemented. Risk assessment incorporates the risk analysis and risk evaluation phases.
The global elements of risk assessment are:

- Risk analysis (estimation of the risks);
- Risk evaluation (process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable leading to a decision recommendation).

The roles for risk assessment in reaching a conclusion on the safety of dams are given in the 2003 Guidelines as (a) an enhancement to the traditional method; (b) an alternative to the traditional approach; and (c) a sole basis for decision making. At the time of the Guideline publication, ANCOLD only supported the first of these roles for important and conclusive decision making with regard to dam safety. In using the risk-based approach, the intention was to extend the understanding gained from the traditional approach as it was recognised that the traditional approach was not well suited to some issues of dam safety, including spillway gate and operating system reliability, human factors and the safety of embankment dams against piping where the dams do not have the contemporary defensive design measures (such as fully intercepting filters).

Dam safety is covered by State legislation in Australia and there is no role for the Australian Federal Government. Since publication of the Guidelines, the application of risk assessment techniques have evolved and some of the States within Australia have accepted the use of both the traditional and risk assessment techniques for the safety regulation of dams. While risk assessments are often thought of in the context of “Dam Safety” following construction, considerable emphasis is now being placed on the Safety in Design applications within Australia. Furthermore, risk assessment practices are routinely being followed in the design and ongoing operation and maintenance of tailings dams.

The following sections provide an overview of the practices currently being followed within the Australian States with regard to the application of risk assessment in dam safety management, as well as Safety in Design and application of risk assessment to Tailings Dams. Information is also provided as to the status of the 2003 ANCOLD Risk Assessment Guidelines supporting information.

**DAM SAFETY MANAGEMENT AND THE APPLICATION OF RISK ASSESSMENT IN AUSTRALIA**

**Risk Assessment in Dam Safety Management - The Context**

The ANCOLD 2003 Dam Safety Management Guidelines state, “The objective of dam safety management is to protect life, property (e.g. community infrastructure, dam) and the environment from the failure of any dam. This objective can be achieved by implementing and maintaining an appropriate dam safety program.” Figure 1 shows the main activities of a typical dam safety program, which includes design, construction,
surveillance, operation and maintenance, safety review, risk assessments, remedial action, education and training and emergency preparedness. As shown on this figure, risk assessment is considered to be one of the foundation elements to identifying a deficiency and taking the necessary action to remediate the issue at the dam, should this be required.

Figure 1. Elements of a Typical Dam Safety Program (ANCOLD 2003a)

**Roles of Risk Assessment**

All of the states within Australia have applied risk assessment in some form varying from portfolio risk assessments to the more detailed risk assessments during the decision making process for upgrades. In particular, Victoria has made use of risk assessment for continuous and progressive safety improvements of dams across the State and has a well developed framework for the evaluation of dam safety based on risk. One of the major dam owners in Tasmania (Hydro Tasmania) has also been applying risk assessment since 1999 and uses risk assessment as the basis for their remedial works programme and for surveillance and operation maintenance programmes.

**Role of Government**

“A role of government is to enact legislation to protect the community. Legislation should establish regulatory authorities that ensure dam owners, and potential dam owners, are taking appropriate actions in regard to dam safety.” (ANCOLD 2003a)

Dam safety legislation varies throughout Australia with regulation as follows:

- New South Wales (regulated), NSW Dams Safety Committee (DSC)
- Queensland (regulated), Department of Environment and Resource Management (DERM)
- Victoria (regulated), Department of Sustainability & Environment (DSE),
- Tasmania (regulated), Department of Primary Industries, Water and Environment (DPIWE)
- Australian Capital Territory (ACT) (regulated), Department of Urban Services (DUS)
- South Australia (Self regulated)
- Western Australia (Self regulated)
- Northern Territory (Self regulated)

The application of the regulations with the States applies for dams with the limits and approximate number of regulated dams in each State shown on Table 1 (Sih 2010).

Table 1. Criteria for Determination of Regulation within Australian States

<table>
<thead>
<tr>
<th>State</th>
<th>Criteria for Regulation</th>
<th>Number of Regulated Dams</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACT</td>
<td>Scheduled Dams</td>
<td>6</td>
</tr>
<tr>
<td>New South Wales</td>
<td>Low consequence category dams &gt; 15 m height and all Significant, High and Extreme consequence category dams</td>
<td>346</td>
</tr>
<tr>
<td>Queensland</td>
<td>Population at risk (PAR) ≥ 2 people, A Failure Impact Assessment to determine PAR is automatically required if dam is: Height &gt; 8 m and Capacity &gt; 500 ML or Height &gt; 8 m and Capacity ≥ 20 ML and catchment area &gt; 3 times surface area of the dam at full supply level; If the regulator determines there is likely to be PAR for other dams, dam owners can be directed to undertake an assessment.</td>
<td>106</td>
</tr>
<tr>
<td>Tasmania</td>
<td>&gt; 1 ML or on a stream</td>
<td>260 &gt; Significant 8040 Other</td>
</tr>
<tr>
<td>Victoria Water Corps.</td>
<td>All Water Corporation Dams with Significant or higher ANCOLD Hazard category; or Height ≥ 8 m and Capacity ≥ 500 ML; or Height ≥ 10 m and Capacity ≥ 20 ML; or ≥ 15 m</td>
<td>250</td>
</tr>
<tr>
<td>Victoria Private dams</td>
<td>On a waterway and is potentially Significant or higher ANCOLD Hazard category; or Height ≥ 8 m and Capacity ≥ 500 ML; or Height ≥ 10 m and Capacity ≥ 20 ML; or ≥ 15 m</td>
<td>700</td>
</tr>
</tbody>
</table>
**Regulation**

*Regulation involves the imposition of rules or principles intended to influence the behaviour of people and/or businesses, supported by the authority of the government. Government regulation can be viewed as a continuum, with mandatory, enforceable regulation (i.e. imposing penalties for non-compliance) at one end and self-regulation at the other (Government of Victoria 2007).*

Legislation is the most explicit form of government regulation, either primary legislation, namely Acts of Parliament, or subordinate legislation, such as statutory rules. (Government of Victoria 2007). Legislation or rules describe the powers and role given to the regulating body and the responsibilities of the people being regulated.

*Self-regulation is generally characterised by the development of voluntary codes of practice or standards by an industry, with the industry solely responsible for enforcement, and where the Government’s role may be non-existent, or limited to the provision of advisory information* (Government of Victoria 2007). The usual laws of tort apply for dam safety incidents involving third parties.

**Role of Dam Safety Regulator**

The role and responsibilities of the Regulator are generally given in the respective State regulations and the regulatory authorities maintain a register of the dams under their jurisdiction. The Regulators have the power to ensure that dams are designed, operated and maintained in accordance with currently accepted standards. In some States, this now includes the use of risk assessment as a means of prioritising and/or justifying upgrades for dam safety, as discussed below.

**APPLICATION OF RISK ASSESSMENT WITHIN AUSTRALIA**

**Queensland**

**Regulation Guidelines**

Dams that have been identified as potentially requiring regulation are required to have a failure impact assessment (FIA) done by the owners to determine the Category of referability (Category 1 = 2<PAR<100 or Category 2 = PAR >100). The FIA is submitted to the Chief Executive for DERM who then regulates the dams through Safety Conditions imposed under the Water Supply (Safety and Reliability) Act 2008. These conditions include the requirement for compliance with the DERM “Guidelines for Acceptable Flood Capacity”, which 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. Where dams fail to comply with the AFC requirements, dam owners are required to remediate
the dams to the required capacity in accordance with the schedule of times shown on Table 2.

Table 2: Schedule for Dam Safety Upgrades (Queensland DERM)

<table>
<thead>
<tr>
<th>Tranche</th>
<th>Required minimum flood discharge capacity</th>
<th>Date by which the required minimum flood capacity is to be in place for existing dams</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25% of AFC or 1:500 AEP flood event (whichever is the bigger flood)</td>
<td>These dams must be upgraded as soon as possible</td>
</tr>
<tr>
<td>2</td>
<td>50% of AFC or 1:2000 AEP flood event (whichever is the bigger flood)</td>
<td>1 October 2015</td>
</tr>
<tr>
<td>3</td>
<td>75% of AFC</td>
<td>1 October 2025</td>
</tr>
<tr>
<td>4</td>
<td>100% of AFC</td>
<td>1 October 2035</td>
</tr>
</tbody>
</table>

The AFC guidelines present three methods for assessing the AFC for referable dams:

- **Small Dams Standard**

The method allows the owners of small earth dams with PAR less than 15 to quickly assess spillway adequacy. It is a simplified “Fall-back” method, which relates the Acceptable Flood Capacity Annual Exceedance Probability (AEP) directly to the population at risk using Equation 1

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

Equation 1

- **Fall-back option**

The Fall-back option is intended for larger dams where the cost of undertaking a full risk assessment is not warranted when weighed against the potential benefits. The fallback spillway capacity relates the hazard rating to the required design flood capacity using a matrix of Incremental Population at Risk and Severity of Loss and Damage. The floods range from an AEP of 1 in $5 \times 10^{-4}$ to the PMF.

- **Risk Assessment Procedure (incorporating ALARP).**

The risk assessment procedure is based on the ANCOLD risk assessment process and was proposed to be adopted for all major dams. In particular, the risk assessment approach has allowed the evaluation of gated spillway reliability and the likelihood of premature failure due to causes such as spillway erosion.
This method relies on the use the ANCOLD guidelines to determine the annual probability of dam failure. *Graham’s Method* (Graham, 1999) is used for estimating loss of life (LOL) due to dam break flood events while for natural flood events, the LOL is estimated using a factor of 0.001 to 0.0001 PAR. The incremental life loss is then used in the evaluation of individual and societal risk for comparison against the ANCOLD limits of tolerability. The Societal Risk is shown on Figure 2 while the individual risk is $10^{-4}$ for existing dams and $10^{-5}$ for new dams.

![Figure 2. Application of ALARP to bring Societal Risk below Limit of Tolerability](image)

Where dams exceed the societal or individual risk, upgrade options are required to lower the risk to the tolerable level after which the upgrades are assessed for compliance using the ALARP principle by formulating additional risk reduction options that would bring the risk profile further below the limit of tolerability with an acceptable cost benefit ratio of less than 1.0. The cost benefit ratio is calculated for a lifetime of 150 years and is based on the following.

- Incremental project costs and benefits to reduce the risk profile beyond the limits of tolerability. The expected cost of the upgrade also allows for the calculation of the Net Present Value using the cash flow for the annual construction costs and a discount rate of 6% as noted in the Queensland Treasury Guidelines.

- A Value of a Statistical Life (VOSL) of AU$5 million (in 2004 dollars);

**Application of the Guidelines**

Based on the analyses completed to date, the predominant risk in Queensland results from spillway inadequacy although piping risks can be significant for some dams. Within Queensland, there are two organisations that own the majority of the larger dams namely SunWater and South East Queensland Water (Seqwater).
SunWater owns 22 dams within their portfolio and risk assessments have been carried out based on hydrological events only to identify those dams in the portfolio with the highest risk not meeting the ANCOLD limits of tolerability for either individual or societal risk. Recently, SunWater has developed a more comprehensive 6 step approach using both the Standards Based Approach and a Risk Based Approach where the objective is to meet the Board’s policy

“That SunWater’s referable dams shall be upgraded to 100% of Acceptable Flood Capacity as determined by the traditional standards based approach, except where it can be demonstrated that the cost of an individual dam upgrade is grossly disproportionate to the benefit gained.

SunWater will consider each dam on a case by case basis. Where it can be demonstrated that the cost of an individual dam upgrade is grossly disproportionate to the benefit gained, SunWater will determine the extent of the required upgrade, which will at least achieve 100% of Acceptable Flood Capacity as determined by the risk assessment approach, in consultation with shareholding Ministers. The upgrade of SunWater’s dam portfolio will be prioritised based on overall risk.”

In determining an ALARP position, SunWater has adopted at least an additional order of magnitude of conservatism compared with the ANCOLD Guidelines. Sunwater also uses a measure of disproportionality ratio between the initial preferred fallback position AFC and an AFC based on risk assessment in order to justify any deviation from the Fallback Standards Based Analysis position.

Seqwater have 26 referable dams for which about 10 do not satisfy the current requirements for AFC capacity and require upgrading in accordance with the schedule on Table 2. The formation of Seqwater included ownership of a number of Council and some SunWater dams for which both the risk assessment and fallback approaches have been used to derive the AFC requirements. While the DERM schedule gives guidance as to when the upgrades are required, there is no way of comparing the portfolio of dams to provide a robust means of justifying the timing and costs for the upgrades. Consequently, Seqwater will be using a risk assessment approach across their portfolio of dams in the near future.

Issues in Application of Risk Assessment within Queensland

- The ongoing challenges associated with the evaluation and calculation the probability of the risk component or event for the quantified risk assessments.
- Discontinuity between flood hydrology (extreme flood estimation) and dam safety engineering where there is a large uncertainty associated with the estimation of the AEP of the Probable Maximum Precipitation (PMP) amount, especially for medium and large dams with small or huge catchments. This is leading to the conclusion that risk assessment cannot be applied at present for one dam in particular which has a
catchment area of about 114,000 km\(^2\) and for which the notional AEP of the PMP is 1 in 10,000, resulting in intolerable levels of risk, which cannot be mitigated.

**New South Wales**

Risk Assessment is being applied within NSW in the following areas:

- To guide priority and urgency through portfolio risk assessment;
- To assess public safety risks during the construction of dams;
- To review the safety of individual existing dams;
- To determine the need for individual dam safety improvement projects.

The 1978 *Dams Safety Act* was enacted to constitute the Dam Safety Committee and to confer and impose on the Committee functions relating to the safety of certain dams. The Committee represents the Crown and comprises nine part-time members appointed by the Minister. Eight members are to be experienced in Dam Engineering and the ninth member has traditionally been experienced in Mining. Members are nominated by various organizations, government Ministers and Engineers Australia.

The DSC’s mission is to “ensure the safety of dams”. Its corresponding vision is that

- All dams meet a level of safety that is acceptable to the community and
- The DSC inspires confidence in its stakeholders and is recognized for its technical excellence.

In August 2006, the Risk Management Policy Framework for Dam Safety was endorsed by the Government and is now incorporated into NSW Dams Safety Committee, 2010 guidance sheets that cover a range of topics for ensuring the safety of dams. In particular, the policy framework is fully reproduced in *Background to DSC Risk Policy Context DSC1B* June 2010. Risk assessment was accepted as a tool to assist dam safety management and the application of the policy includes a tolerability framework for public safety risks.

A full suite of guidance sheets, including implementation of risk assessment was launched at a workshop in June 2010 with a key sheet being the “Demonstration of Safety for Dams” DSC2D June 2010 ([http://www.damsafety.nsw.gov.au](http://www.damsafety.nsw.gov.au)). This guidance sheet covers a number of important matters involved in the safety review of dams including:

- hazards and failure modes where the traditional engineering Standards Based Approach (SBA) is to be considered;
- DSC requirements for risk assessments;
- guidelines for undertaking failure modes analysis (FMA);
– the qualifications and experience of persons undertaking risk assessments;
– the need for peer review of safety review reports;
– guidelines for demonstration of ALARP;
– the application of the safety case concept to dams;
– application of the concepts of prevention, control and mitigation (PCM) to dams.

Risk Assessment is either required by the DSC or is appropriate where:

1. There are aspects not adequately addressed by traditional standards or good practice and those aspects are significant in assessing the safety of a dam - risk assessment required by DSC;
2. An owner wishes to demonstrate that less costly safety improvements, than those required by standards or good practice, would adequately protect public safety and community interests - risk assessment required by DSC;
3. An owner wishes to undertake risk assessment as a basis for more informed decision making – risk assessment is at owner’s discretion.

Principle D3 of the DSC Guidance Sheet DSC1B states “when required to do so, a dam owner is to demonstrate that risks to public safety and other interests of the community are tolerable. To be tolerable, a risk must be as low as reasonably practicable (ALARP). For public safety risks, risk boundaries – the limit of tolerability and the negligible level of risk – are relevant in applying the ALARP test.”

The criteria for individual risk are the same as ANCOLD (1E-4/Annum for existing dams and 1E-5/Annum for new dams) while the societal risk acceptance differs slightly from the ANCOLD criteria, as shown on Figure 3. Owners or proponents are required to demonstrate that both risk to the individual and societal risk are ALARP on the basis of:

- The disproportion between the sacrifice (money, time, trouble and effort) in making the safety improvement and the risk reduction that is achieved.
- the level of risk in relation to the limit of tolerability and the negligible risk level;
- the cost-effectiveness of safety improvement options;
- any relevant recognized good practice; and
- societal concerns as revealed by the owner’s or proponent’s consultation with the community and other stakeholders.
Community consultation is required and must be provided to the DSC as one essential basis for any ALARP decisions that are made and, as shown on Figure 3, where the loss of life is estimated to be greater than 1000, the DSC expects full compliance with the relevant Standards Based Approach (SBA). Owners can avoid the need to demonstrate that risks are ALARP by a commitment to reduce risks to the negligible level.

The concept of progressive improvement of safety has developed as the result of risk assessment for dams and consideration of the extremely high cost-to-save-a-statistical-life (CSSL) values to improve safety where risks are below the limit of tolerability. The concept, which is outlined in DSC1B, can be applied to any situation where there is a sensible intermediate fix but to date has mainly been applied to improvements in flood capacity.

Loss of life estimation from dam failure is estimated using Graham 1999 while loss of life from flood without dam failure is based on Hill et al 2007. The “Piping Toolbox” (USBR et al 2008) and supporting document is being applied for the estimation of piping through embankments and foundations.
Victoria

Dam Safety is regulated under the Victoria Water Act 1989. The Department of Sustainability and Environment (DSE) has a regulatory role and provides the following functions:

- Dam safety policy;
- Governance/regulatory role;
- Lead agency during dam safety incidents/emergencies.

Private dams in Victoria are regulated through a licencing process while Water Corporation dams are regulated through “Statements of Obligations”. The latter specify obligations that the authority has in performing its functions or exercising powers that it has under the Act. The Statements of Obligations include clauses relating to the following issues, which make specific reference to ANCOLD Guidelines in relation to developing and implementing processes to identify, assess and manage dam safety risks:

- Risk Management;
- Asset Management;
- Dam Safety;
- Emergency Response.

The Dam Safety Obligations require the owners to:

- have regard to the ANCOLD Guidelines;
- prioritise risks posed for all of the dam components and types of failure;
- give priority to reducing risk to life over other risks;
- base the urgency of reducing risks relative to the ANCOLD tolerability limits;
- base the programme for reducing risks on the concept of ALARP;
- where feasible, progressively implement risk reduction measures to achieve the best outcomes with the available resources.

Victoria was the first Australian State to require dam owners to adopt risk based practices. Sixteen water authorities own large dams, which are used for wholesale, retail, irrigation, recreation, etc. Large dam owners in Victoria commenced the use of risk assessments in late 1990s to make key decisions in dam safety management. There are close to 250 dams that have undergone some form of risk assessment, from a portfolio level to a very detailed. Methods of analysis include the use of the “Piping Toolbox” (USBR et al August 2008), while loss of life estimates have generally been developed using the USBR approach (Graham 1999).

Guidelines were developed in 2007 to assist Victoria Water Corporations in providing their annual Dam Safety Report to the DSE, as required under the Statement of Obligations. An Excel based dam safety reporting template was developed for use by
Water Corporations to encourage a more consistent approach to the submission and collation of dam safety information across Victoria. The information is provided to the regulator using templates labelled from A to I and includes general details on the dams, ANCOLD hazard category, surveillance data, Dam Safety Emergency Plan details, incident details, upgrade data, standards based assessment data and where appropriate, risk based assessment data.

Having the above information has provided a State wide perspective of risk and dam safety management and has also allowed the measurement of risk reductions over time and also against investments made. This in turn is assisting in progressive and continuous as well as better targeted improvements in dam safety.

**Issues in Application of Risk Assessment in Victoria**

- The risk management process / methodology needs further work.
- Comparing risks derived from different levels of risk assessments can pose a challenge. This can, however, be addressed by identifying the uncertainty band and treating them as such.
- The most important issue is the use and interpretation of the ALARP principle. Given that many dam owners are now in the ALARP zone, this is a critical area that requires guidance and further development.

**Tasmania**

The responsible authority for dam safety in Tasmania is the Department for Primary Industries, Water and Environment with Dam Safety being controlled under the Water Management Act 1999 and the Water Management (Safety of Dams) Regulations 2003. While the use of risk assessment is not explicitly legislated, Clause 165C part (f) of the Water Management Act 1999 states that one of the functions of the Minister is “to formulate measures to ensure the safety of dams and, in particular, plans to remove or minimise risks to persons or property or the natural environment arising from an incident”.

In Part 2 of the Water Management (Safety of Dams) Regulations 2003, the standards for design state:

“A person must not carry out any work for the purpose of, or in connection with, the design, construction, surveillance or decommissioning of a dam unless the person meets the required competency standards specified in these regulations and carries out the activity

(a) in accordance with these regulations; and

(b) in accordance with the most appropriate industry practice; and
An Assessment Committee advises the Minister on matters relating to dam safety, including risk and these relatively non-prescriptive regulatory requirements allow the sound application of the ANCOLD Dam Safety Management and Risk Assessment Guidelines which in large part shape the Dam Safety Assurance Program for Hydro Tasmania, which is Australia’s largest dam portfolio owner and manager.

The Safety Regulations also specify the levels of competence required for carrying out the dam design, construction, surveillance, safety reviews and decommissioning for dams of hazard category varying from very low to Extreme. This ensures that the appropriate levels of expertise are used in the overall safety of the dams. This is similar to Queensland where the majority of dam safety and design related issues are required to be carried out by a Registered Professional Engineer in Queensland (RPEQ).

Risk Assessment in Hydro Tasmania
Many of the Hydro Tasmania dams were at the leading edge of dams engineering at the time of their development and have contributed to the definition of accepted practice, particularly for concrete faced rockfill dams (CFRD). Hydro Tasmania has been applying Risk Assessment since 1998 when risk assessment was primarily targeted at the fifty five referable dams in the portfolio but intended to encompass the 150 lesser structures in their portfolio of dams.

Hydro Tasmania has a business wide Integrated Business Risk Management framework (IBRM) which includes risk criteria for, health and safety, environmental and social, financial, legal, stakeholder and business strategy loss categories. At the highest level the IBRM risk assessment categorizes risks as Low, Moderate, High or Extreme. The Dam safety Risk Management Policy successfully aligns the societal risk tolerability criteria included in the 2003 ANCOLD Guidelines on Risk Assessment with the IBRM criteria, as shown on Figure 4. This is a very powerful method of transparently rating dam safety risks against other asset and business risks. The Policy then describes the organizational response required for the risk categories described above.

The process of managing dam safety in Hydro Tasmania attempts to achieve the best balance between compliance with good practice and engineering standards and the tolerable management of risk. The dam safety program is accordingly arranged into two streams focussed on these objectives and titled “Compliance” and “Risk Management” respectively. A significant management and governance function of the program is to ensure that a suitable balance of effort and progress is maintained between the two streams.
The first stage of the Portfolio Risk Assessment (PRA) commenced in 1998 with a pilot study of four dams, selected to assist in the development of the engineering assessment process for various dam types and potential failure modes. The engineering assessments have involved a range of hydrological studies, geotechnical investigations, failure modes workshops and event tree development including use of the “Piping Toolbox”.

The consequence assessments were also undertaken, considering life safety risk (both societal and the individual most at risk) generally using the USBR approach (Graham 1999), financial and economic loss modelling, environmental and other potential consequences. When completed in 2006, all 55 referable dams had been assessed following a standardised methodology and a simplified method had been applied to the lesser dams, none of which were deemed to pose a life safety risk.

In all, ten dams were assessed to lie outside the ANCOLD societal risk tolerability limit and, therefore, the IBRM limit of tolerability. An additional three dams were assessed to fall outside Hydro Tasmania’s own financial risk (IBRM) tolerability. A more detailed risk assessment was then performed to confirm the assessment and better constrain the field of available mitigation treatments. To date mitigation works have been undertaken to reduce the risk to an acceptable level at eight of these dams.

**Treatment of Intolerable Risks**

The general process to treat intolerable risks has been to:

i) investigate and undertake “quick win” risk reduction works where possible to achieve an interim level of mitigation. This has included improved flood monitoring and emergency response planning, site works to close gaps or low
points which give a reduced flood discharge capability, enhanced surveillance and monitoring, potentially reduced loading;

ii) develop a range of mitigation options including specific measures to treat identified failure modes and what might be considered “full standards based upgrades”;

iii) cost, rank and prioritise the various mitigation options both for each dam and across the portfolio;

iv) apply the ALARP principle to determine which mitigation options, combination and sequencing of options provides the best risk mitigation value; and

v) produce an intended risk reduction pathway for the each dam and the portfolio of intolerable risk dams.

The above process has become iterative and an internal review process was developed to take account of new information and better assessment tools which affect the understanding of observed issues.

**Western Australia**

Dam safety legislation drafted in the late 1970s was passed through Parliament but the legislation was never enacted. The Water Corporation was formed in 1995 and provides water and wastewater services across the state of Western Australia. The Water Corporation is the major dam owner in Western Australia with responsibility for about 100 dams. Although there is no specific dam safety legislation in Western Australia, the Emergency Management Act 2005 requires the Corporation to “adopt current national ANCOLD.” This includes “maintaining a dam safety remedial works program to progressively reduce the risk of dam failure” (Somerford 2007). Tailings and other dams associated with the mining industry are covered by Legislation under the Mines Act and aside from the mining industry there are a number of other owners of Large Dams in West Australia, but as there is no legislation in place and these dam owners have no statutory oversight.

The Water Corporation, which is self regulating, has since 1999 had a dam safety management program in place that is based on compliance with ANCOLD guidelines. The dam safety management program includes a program of remedial works that has seen over $200 million spent upgrading 25 dams to date. Portfolio risk assessment was originally undertaken in 2000 to better prioritise the program, to strengthen the justification for the program and to facilitate benchmarking against other dam owners in Australia.

Dams represent only about 15% of the Water Corporation’s asset base and there are many other sources of risk (for example, new water sources, upgrades to meet drinking water guidelines, prevention of sewage spills etc) that compete for limited funds. In 2009 the Water Corporation moved away from using portfolio risk assessment to prioritise dam safety projects. Instead dam safety projects were included in a risk assessment process that is applied across all Corporation assets to prioritise projects across the Water Corporation’s Capital Investment Program (CIP). A score is assigned to each project based on a matrix of six consequences and six levels of likelihood. There were problems
with the application of this process to dam safety because of the low probability of failure resulting in low scores for all dam safety projects. The result was little funding for dam safety projects despite the Corporation owning eleven dams with unacceptable life safety risks. To determine the funds available for dam safety remedial works, the Water Corporation is now moving to strategic capital prioritisation that will review dam safety within the context of the Water Corporation’s total business. Portfolio risk assessment will then be used to prioritise projects within the funding allocated to dam safety.

While dam safety risk assessment has proved a valuable tool to prioritise the Corporation’s dam safety projects within the dam safety program, the key issues the Corporation continues to grapple with are:

- How to prioritise the dam safety projects against other projects across the capital investment program?
- What is a “reasonable” rate to proceed with the remedial works program?

There are also concerns within the Water Corporation with respect to the application of ALARP and in particular the Cost to Save a Statistical Life, which is not considered to be effective as a management tool. Greater emphasis is being placed on Good Practice and the statement by the UK Health and Safety Executive “HSE expects authoritative good practice to be met as a minimum use” (Somerford, 2007). This in itself has also proven to be difficult in application because some failure modes do not have “standards” for application to the problems eg piping.

Safety in Design

Safety in Design (SiD) is not explicitly addressed in the ANCOLD Guidelines on Risk Assessment, however, SiD principles are included within all states in Australia with specific requirements in Queensland and South Australian legislation for full risk assessments to be undertaken on design hazards. The National Model Work Health and Safety Bill currently being rolled out across Australia is less prescriptive and Workplace Health & Safety in Australia is in the process of nationalising the legislation. The Safe Work Australia website provides overall legislation and principles for Safety in Design (SiD) as follows.


Given that Safety in Design is in legislation, it is no longer sufficient to assume that compliance with a code or standard is enough. SiD principles are required to be applied throughout the life and use of the "Facility" that is being designed while ensuring the clients is aware of the residual risks. The key elements that impact on implementing SiD are shown on Figure 5 and discussed below.

**Principle 1: Persons with Control** – persons who make decisions affecting the design of products, facilities or processes are able to promote health and safety at the source.
**Principle 2: Product Lifecycle** – safe design applies to every stage in the lifecycle from conception through to demolition. It involves eliminating hazards or minimising risks as early in the lifecycle as possible.

**Principle 3: Systematic Risk Management** – the application of hazard identification, risk assessment and risk control processes to achieve safe design.

**Principle 4: Safe Design Knowledge and Capability** – should be either demonstrated or acquired by persons with control over design and should reflect the knowledge that a competent designer would be expected to have.

**Principle 5: Information Transfer** – effective communication and documentation of design and risk control information between all persons involved in the phases of the lifecycle is essential for the safe design approach.

Designers need to demonstrate that they have identified the risks in their design and where a particular code/standard is not appropriate to eliminate these risks; a systematic risk based approach should be used to determine the right solution. As such, Safety in Design is being applied by some organisations and construction alliances and can be defined as:

*The integration of hazard identification and risk assessment methods early in the design process to eliminate or minimise the risks of injury throughout the life of the product being designed.* (GHD 2010)

An approach used for safety in design is as follows (GHD 2010):

- Establish the context for the design - Confirming how all job stakeholders should work together is an integral part in establishing the risk management process;
- Foreseeable uses of the design – the designer should identify the client’s main objectives and outcomes of the design. This information is important to establish the intended and foreseeable uses of the design;

- Safety in Design Risk Assessment – This should be developed and updated regularly during the design and is based on the use of a risk matrix for rating the risk with likelihood and consequences determined during one or more workshops for the various areas of the design. All safety related decisions, including justifications for why Potential Control Measures are not selected, should also be included within the Safety in Design Risk Assessment. An appropriate control for hazards and associated risks is shown on Table 3;

- Communicate and Consult - Consult with the client/end user at all stages of the design for effective management of risks and decisions on the implementation of control measures.

The Safety in Design Risk Assessment is a means by which residual risks that have been treated so far as reasonably practicable can be communicated to all parties at the end of the design. Appropriate procedures or processes should be implemented in the workplace to deal with the ongoing management of the residual risks.

Table 3: Heirarchy of Risk Control Measures

<table>
<thead>
<tr>
<th>Eliminate the Hazard</th>
<th>ELIMINATE - Get rid of the hazard out of the workplace.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change the Way the Work is Done</td>
<td>SUBSTITUTE - Try to replace or change plant, substances or materials to lower the risk from the hazard.</td>
</tr>
<tr>
<td></td>
<td>Try to ISOLATE the hazard</td>
</tr>
<tr>
<td></td>
<td>ENGINEERING CONTROL - Design and install equipment to counteract the hazard</td>
</tr>
<tr>
<td></td>
<td>ADMINISTRATIVE CONTROL - Arrange work so people spend less time around the hazard and monitor their understanding of the hazard and the controls</td>
</tr>
<tr>
<td>PPE</td>
<td>PPE - Have people wear protective equipment and clothing while near the hazard</td>
</tr>
</tbody>
</table>

**Tailings Dams**

Tailings dams are dynamic structures which are continuously changing as the deposition of tailings within the structure continues and the raising of the tailings dam wall progresses to final closure. The risk assessments for these dams have generally been applied using a semi quantitative risk matrix approach based on criteria that the owner’s have developed over time and which can be easily applied and understood by their staff.

A limited number of quantified risk assessments have been completed; however, there have been some difficulties in relating the outcomes to the Client’s decision makers who are not familiar with some of the concepts for ALARP including CSSL and individual
risk probability estimates. Notwithstanding this, the quantified risk assessments have been useful when presenting the outcomes to the Dam Safety Regulators, who are conversant with the various risk assessment approaches.

**REVIEW OF ANCOLD RISK ASSESSMENT GUIDELINES AND DEVELOPMENT OF SUPPORTING INFORMATION**

At a pre-conference workshop to the 2008 ANCOLD Conference, a half day session was held with the aim of obtaining "guidance as to whether, in the light of current experience, there is a need to revise or update the 2003 Guidelines on Risk Assessment.” Issues raised at the workshop were subsequently posted to the ANCOLD website along with most of the presentations made. On 8th February 2010 a meeting of a small group of risk assessment practitioners was convened to consider the comments made at the 2008 workshop and any other issues that the group were aware of.

The group was able to reach a consensus that the Guideline contained next to no information that could be considered to be incorrect and that the Guideline remains an important resource for the Industry. The group also agreed that there is a need for a “Supplement” or “Practice Note” to the 2003 ANCOLD Risk Assessment Guidelines to be produced covering a number of issues in order to:

- re-emphasise practice that is important but is not generally being followed (11 issues);
- provide explanatory notes to update practice or enhance guidance already provided (10 issues) and,
- introduce new concepts that should be included in current practice (11 issues).

Table 4 provides a summary of these new issues or concepts.

Table 4: Summary of New Concepts for Consideration in ANCOLD Risk Assessment Guideline Supplement

<table>
<thead>
<tr>
<th>ISSUE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Is the F-N plot truly a Complementary Cumulative Distribution Function (CCDF)?</td>
</tr>
<tr>
<td>2</td>
<td>Consideration of David Bowles’ proposal to rename limit of tolerability the limit of unacceptability.</td>
</tr>
<tr>
<td>3</td>
<td>Need for guidance on timeframes for risk reduction.</td>
</tr>
<tr>
<td>4</td>
<td>Explanation of de-minimus considerations.</td>
</tr>
<tr>
<td>5</td>
<td>Horizontal truncation on the societal risk guideline – is this still appropriate?</td>
</tr>
<tr>
<td>6</td>
<td>Potential for guidelines for tolerable environmental, social and financial consequences.</td>
</tr>
<tr>
<td>ISSUE</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>-------</td>
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</tr>
<tr>
<td>7</td>
<td>Potential for guidance on how to manage short duration risk.</td>
</tr>
<tr>
<td>8</td>
<td>Should the role of risk assessment be re-addressed?. Sub section 4.3 states that ANCOLD will only support the use of risk assessment as ‘an enhancement to the traditional approach’ and ‘a decision not to meet the SBA norm should be a rare exception.</td>
</tr>
<tr>
<td>10</td>
<td>How to allow for PMF concepts in risk based assessments and in design of upgrades? Should PMF be a fall back design criteria? Similarly, the MCE in earthquake loads.</td>
</tr>
<tr>
<td>11</td>
<td>Several tables in the guideline and much of the references in the commentary need up-dating.</td>
</tr>
</tbody>
</table>

**SUMMARY AND CONCLUSIONS**

The current use of the 2003 ANCOLD Guideline on Risk Assessment and application of risk assessment techniques have evolved within the Australian States to the point where Australian dam engineers have found much value in risk assessment and extensive use is being made by some State Regulators and dam owners in the application of risk assessment for decision making.

This Paper has provided a view of the variations in application of the risk assessment within Australia, which is a clear indication of the flexibility allowable within the application of the ANCOLD 2003 Guidelines on Risk Assessment. It is also clear that there is considerable support provided to the ongoing development of risk assessment by professionals from all States and from both the government and private sector. ANCOLD has strongly supported this collaboration and has been an effective forum for this cooperation to date. The current review of the 2003 Guidelines on Risk Assessment has been encouraged by ANCOLD and the review will re-emphasise practice that is important and generally not being followed and is also expected to provide more guidance in the application of risk assessment and introduce important new concepts that should be included in current practice.

**REFERENCES**

ANCOLD 2003a, Guidelines on Dam Safety Management, Australian National Committee on Large Dams Incorporated, Australia

ANCOLD 2003b, Guidelines on Risk Assessment, Australian National Committee on Large Dams Incorporated, Australia


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