

# PORTFOLIO RISK ASSESSMENT OF SA WATER'S LARGE DAMS

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## ABSTRACT

*This paper summarises the Portfolio Risk Assessment (PRA) process that was implemented for SA Water's 17 large dams, the information obtained from the PRA, and its use by SA Water. The PRA was designed to provide a baseline assessment of the existing dams and an initial prioritisation of future investigations and possible risk reduction measures. The PRA comprised a reconnaissance-level engineering assessment and risk assessment. These assessments were performed for floods, earthquakes, and static loading. Various structural and non-structural risk reduction measures were developed and evaluated. Information from the PRA can be used to provide inputs to capital budgeting, due diligence and liability evaluations, contingency planning and business criticality assessment, evaluation of loss financing and insurance programs, and a firm basis for monitoring and surveillance, operations and maintenance, and emergency preparedness planning.*

## INTRODUCTION

The South Australian Water Corporation (SA Water) became a public corporation in July 1995 when it replaced the Engineering and Water Supply Department. It provides water and wastewater services to a population of more than 1 million people throughout South Australia. In 1996 SA Water entered a long term contract with a private consortium, United Water, to manage and operate Adelaide's water and wastewater system. SA Water retained ownership of all assets and continues to manage and operate the country systems and the harvesting and supply of all bulk water.

SA Water operates and maintains 16 large dams as part of the bulk water system and one flood control dam (Table 1). It is self regulated with respect to dam safety and has a good dam safety record. However, more than half its portfolio of large dams are greater than 75 years old, and in many cases they do not meet modern engineering standards. A number of dams are located on streams that run through metropolitan Adelaide where the consequences of a dam failure would be catastrophic.

SA Water will need to make some important choices on how much dam safety improvement is justifiable at each of its dams, how to prioritise these improvements, and at what rate to proceed. Such decisions will be made within the framework of expectations of long term profitability and improving the Corporation's business value. To provide inputs to these important decisions, and in view of the move to risk based decision making on dam safety, SA Water commissioned RAC Engineers & Economists to undertake a Portfolio Risk Assessment (PRA). The primary objective of the study was as follows:

*To undertake a reconnaissance-level Portfolio Risk Assessment of SA Water's 17 large dams and prepare a report which indicates the current risk profile of the portfolio and make recommendations on the ranking and staging of dam safety upgrade studies with the objective of implementing the most cost effective rate of risk reduction.*

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This paper summarises the PRA process as it was applied to SA Water’s portfolio, the information obtained, and its proposed use by SA Water. It includes a comparison with the current approach to prioritising dam safety reviews at SA Water.

**Table 1. SA Water’s Portfolio of Large Dams.**

DAM	TYPE	YEAR COMPLETED	CURRENT REPLACEMENT COST (\$m)	HEIGHT (m)	RESERVOIR CAPACITY (ML)
BAROOTA	Earth	1921	36	30	6,140
BAROSSA	Concrete Arch	1902	15	36	4,510
BEETALOO	Concrete Gravity	1890	28	33	3,150
BUNDALEER	Earth	1903	25	24	6,370
HAPPY VALLEY	Earth	1897	29	24	15,060
HINDMARSH VALLEY	Earth	1917	10	14	475
HOPE VALLEY	Earth	1872	19	21	3,630
KANGAROO CREEK	Concrete faced Rockfill	1969	58	63	19,000
LITTLE PARA	Concrete faced Rockfill	1979	35	53	20,800
MIDDLE RIVER	Post-tensioned Concrete	1968	20	20	470
MILLBROOK	Earth	1918	20	31	16,500
MOUNT BOLD	Concrete Gravity - Arch	1938	40	49	45,900
MYPONGA	Concrete Arch	1962	31	48	26,800
SOUTH PARA	Earth	1958	65	46	44,900
STURT RIVER (Flood Control)	Concrete Arch	1966	14	41	2,180
TOD RIVER	Earth	1922	17	25	11,130
WARREN	Concrete Gravity	1916	13	20	4,770

## PORTFOLIO RISK ASSESSMENT APPROACH

### Procedure

The PRA was designed to provide a baseline assessment of the existing dams and an initial prioritisation of future investigations and possible risk reduction measures. The PRA comprised a reconnaissance-level engineering assessment and risk assessment. These assessments were performed for floods, earthquakes, and static (internal) loading. They were based mainly on available information and thus it is to be expected that additional investigations and detailed risk assessments will be necessary to evaluate the need for specific measures, to update the initial prioritisation, and to develop a “sign off” level of confidence for engineering and risk assessments. Various structural and non-structural risk reduction measures were developed and evaluated. Information from the PRA can be used to provide inputs to capital budgeting, due diligence and liability evaluations, contingency planning and business criticality assessment, evaluation of loss financing and insurance programs, and a firm basis for monitoring and surveillance, operations and maintenance, and emergency preparedness planning. The PRA was performed through a partnership of RAC Engineers & Economists and SA Water.

The following is a list of tasks, which were performed in conducting the PRA [Bowles 1998b]:

- 1.0 Define overall business context and objectives for PRA
- 2.0 Establish business requirements for PRA
- 3.0 Perform engineering assessment of existing dams
  - 3.1 Review available information
  - 3.2 Conduct site visits
  - 3.3 Review flood and earthquake loadings and make regional estimates
  - 3.4 Assess dams against engineering standards
- 4.0 Conduct risk assessment of existing dams
  - 4.1 Identify significant failure modes
  - 4.2 Formulate event tree risk models
  - 4.3 Develop various reservoir relationships
  - 4.4 Estimate system response probabilities

- 4.5 Perform dam break modeling and inundation mapping
- 4.6 Estimate failure consequences
- 4.7 Develop risk models
- 4.8 Conduct existing dams risk analysis
- 4.9 Evaluate existing dams against risk-based criteria and other factors
- 5.0 Conduct risk assessment of risk reduction alternatives
  - 5.1 Formulate structural and non-structural risk reduction measures and develop their cost estimates
  - 5.2 Conduct risk analysis of risk reduction measures
  - 5.3 Evaluate risk reduction measures against risk-based criteria and other factors
  - 5.4 Compute cost effectiveness of risk reduction measures
- 6.0 Integrate PRA results into business processes
  - 6.1 Develop initial priority for the measures
  - 6.2 Estimate capital budget requirements for the measures
  - 6.3 Formulate Dam Safety Improvement Program
  - 6.4 Integrate PRA outcomes into the overall dam safety management program and other business processes

## **Engineering and Risk-based Criteria**

The initial engineering assessment of the portfolio dams was at a reconnaissance-level against current engineering standards and based largely on available information, site visits, and professional judgment. Bowles et al [1997] define engineering standards to include "current state-of-the-art (or practice), meaning the generally accepted present-day approach to dam design, evaluation, and construction."

A rating system, which was developed by RAC (SMEC/RAC 1995), has been found to be useful for the engineering assessment part of PRAs. The rating system is intended to minimise conservative biases which can be introduced into reconnaissance-level engineering assessments when insufficient information is available to make these assessments at a "sign off" level of confidence. While some measure of conservatism may be acceptable if the goal is to make a "final" determination of safety, too much conservatism can exaggerate capital requirements for dam safety upgrades in a PRA. Results of the engineering assessments are recorded using the following ratings:

- "Pass" (P) and "No Pass" (NP) ratings are given when sufficient information is available to make assessments with the normal level of confidence expected in current engineering practice.
- "Apparent Pass" (AP) or "Apparent No Pass" (ANP) ratings are used to indicate the most likely outcome that is expected in the future when sufficient analyses and investigations have been completed to develop the normal level of confidence.

Existing dams and risk reduction measures were also evaluated using life safety criteria developed by the Australian National Committee On Large Dams [ANCOLD 1994, 1996], the U.S. Bureau of Reclamation [USBR 1997], and B.C. Hydro [1993], and an example of economic/financial criteria presented by NSW Government [1993]. In addition, ALARP (as low as reasonably practicable) and de minimis risk considerations were evaluated for all risk reduction measures. Bowles et al [1998b] discusses these considerations, as follows:

*The basis for ALARP is that risks are "acceptable only if reasonable practical measures have been taken to reduce risks" [IAEA 1992]. In practice this is commonly taken to mean that risks have been reduced to the point where it is no longer cost effective to reduce them further. The cost effectiveness of improving life safety [i.e. cost-per- (statistical) life - saved, CPLS] can be used to assess the degree of ALARP justification for a risk reduction measure [Bowles et al 1996].*

*The term, de minimis risk, comes from the Latin, "de minimis non curat lex", meaning the law does not concern itself with trifles [Shortreed et al 1995]. A significance of de minimis risk in dam safety decision making is that "a dam owner may still have a legal obligation to implement a relatively low cost fix (risk reduction measure), even if it is not cost effective" [Bowles et al 1998a]. The de minimis risk concept appears to be related to the common law construct of what a "reasonable" dam owner would do to reduce risk in a particular situation. It should be remembered, however, that under a common law system there is no guarantee that a safety decision, made before a dam failure, will be viewed favorably by a court after the event.*

*ALARP should always be evaluated when risk-based criteria (both limit and objective values) appear to be met by an existing dam, or by a proposed risk reduction measure. De minimis risk should be evaluated when there appears to be no ALARP justification to proceed with a risk reduction measure.*

Four ALARP justification ratings (“very strong”, “strong”, “moderate”, and “poor”) were proposed for the SA Water PRA based on increasing order of magnitude of CPLs. Similarly, four de minimis risk justification ratings (“strong”, “moderate”, “poor”, and “weak”) were proposed based on increasing order of magnitude of the capital cost of risk reduction measures.

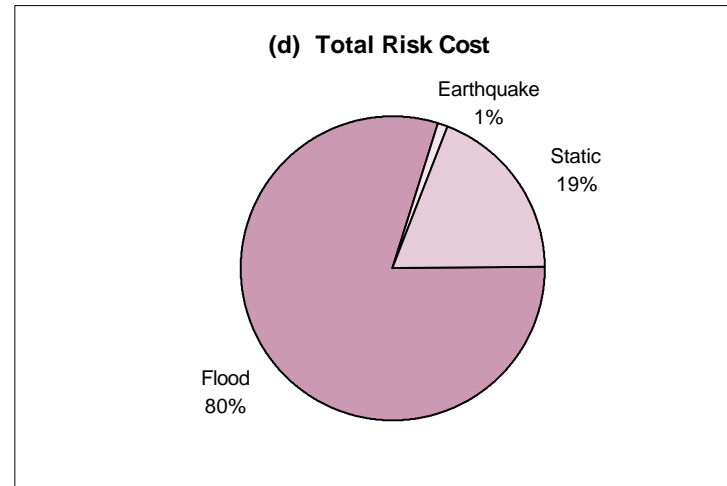
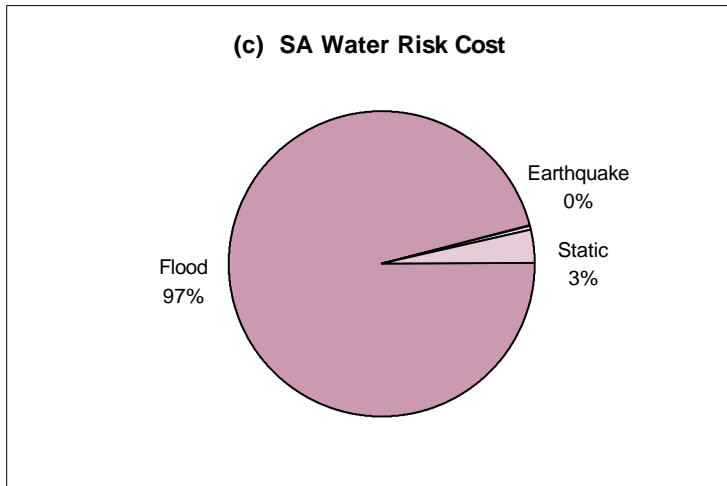
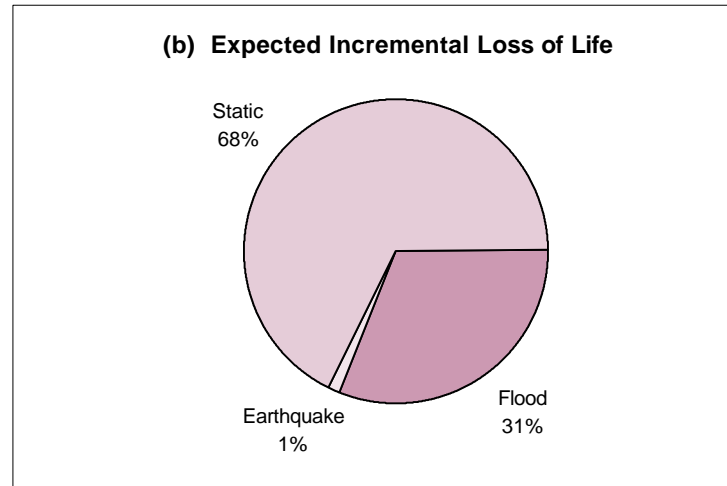
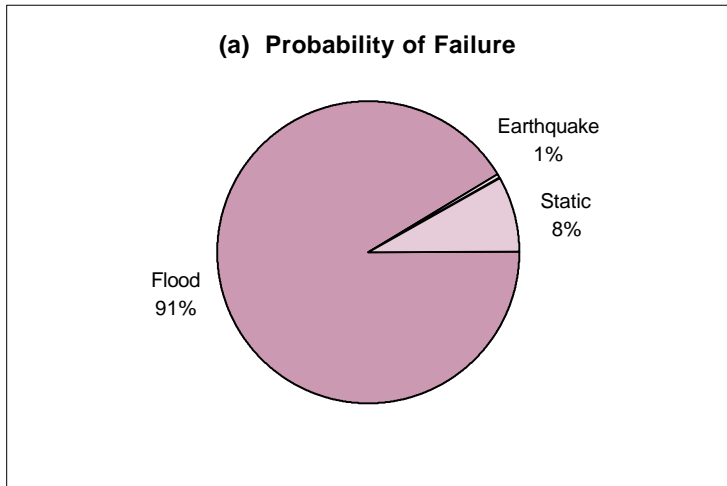
## **STANDARDS-BASED APPROACH VS. RISK-BASED APPROACH**

There are currently no dam safety regulations in South Australia. ANCOLD dam safety criteria may be considered to be de facto dam safety regulations. In Australia and some other countries there is a shift away from the standards-based approach to the risk-based approach for making dam safety decisions. In the risk-based approach the owner (and regulator) decides on the appropriate level of dam safety. This decision should be made in the context of ANCOLD guidelines and the owner’s strategic context, including its purpose, mission, objectives, and the nature of its business. The option of adopting a standards-based level of safety still exists under the risk-based approach, but typically this would be done only if a justification is established based on a detailed risk assessment. In some situations, risk-based criteria may be more difficult to meet than standards. This appears to be the case for some SA Water dams, due to their close proximity to a large downstream population at risk.

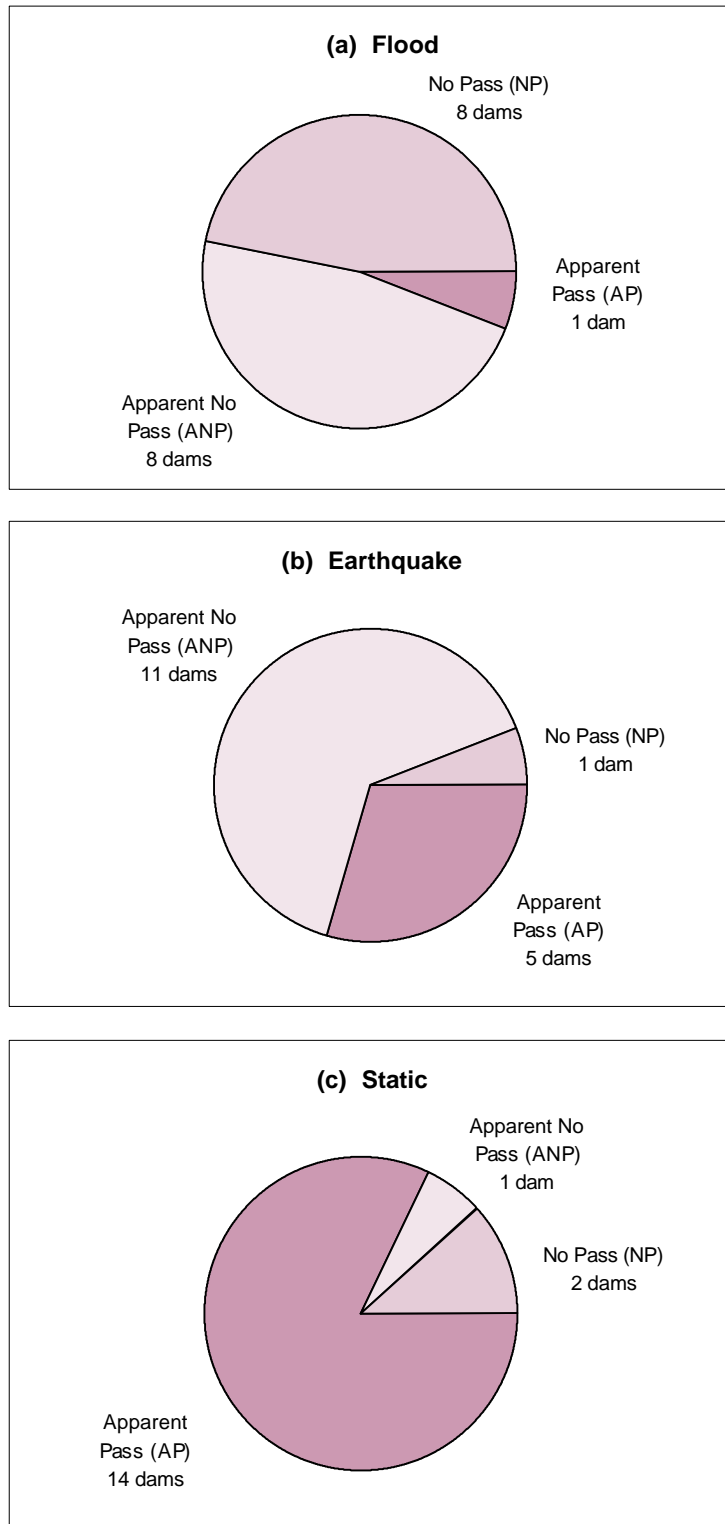
## **EXISTING DAMS - ENGINEERING AND RISK ASSESSMENT**

The outcomes of the engineering and risk assessments of the existing dams are summarised for each type of loading, as follows:

- **Flood Capacity:** Over the portfolio, flood failure modes account for more than 90% of the probability of failure (Figure 1(a)), about 80% of the total risk costs (Figure 1(d)), but only about 30% of the life loss risk (Figure 1(b)). Only one dam is expected to meet flood guidelines (standards) (Figure 2(a)).
- **Earthquake Resistance:** Earthquake failure modes are estimated to contribute about 1% or less to the portfolio probability of failure (Figure 1(a)), total risk costs (Figure 1(d)), and life loss risk (Figure 1(b)). Current practice for earthquake resistance is expected to be met by 5 dams (Figure 2(b)).
- **Static Loading:** Over the portfolio, static loading failure modes appear to contribute less than 10% to the probability of failure (Figure 1(a)), less than 20% to the total risk costs (Figure 1(d)), but almost 70% to the life loss risk (Figure 1(b)), due to lack of warning time needed for evacuation. Current practice for static loading is expected to be satisfied by 14 dams (Figure 2(c)).



**Figure 1** Breakdown of risk associated with each loading type for existing dams



**Figure 2** Engineering assessment ratings assigned for each loading condition over the portfolio of 17 dams

For ANCOLD revised interim societal (life safety) risk criteria, five dams do not appear to meet the limit criterion, and an additional six dams do not appear to meet the objective criterion. A comparison of life safety risks for the existing SA Water dams with a representative sample of Victorian dams [SMEC/RAC 1995] shows that they have a generally similar risk profile. However this benchmarking exercise did highlight the relatively high life safety risks at some dams and a high probability of flood-induced failure at another dam.

## **RISK REDUCTION MEASURES - RISK ASSESSMENT**

A total of 23 structural risk reduction measures were formulated at a reconnaissance level as logically separable construction packages. Each measure was developed with the intent of meeting an engineering standards level of risk reduction. Even so, some are not expected to meet ANCOLD or other societal risk criteria for life loss, due to their close proximity to a population at risk. Measures were not developed for two dams which appear to meet standards requirements for all loadings except for floods, but for which overtopping is not expected to lead to dam failure.

Structural measures usually achieve life loss risk reductions by lowering the probability of dam failure. In contrast, early warning systems (EWSs) are designed to increase warning time with the goal of reducing life loss due to dam failure. The benefits of EWS's were evaluated in an indicative manner for the existing dams, based on assumed increases in warning time. Significant reductions in estimated life loss were indicated for EWS's.

Benefit:cost ratios greater than one were identified for only two structural measures: installing external back-up seals on the upstream face of a concrete faced rockfill dam (approximately 2:1); and stabilising a free standing crest structure used for raising a dam in the 1960's (greater than 40:1). Net present value is estimated to be positive for only the second of these structural measures.

Of the 23 structural measures considered, there are three "very strong" ALARP justification ratings, three "strong" ratings, three "moderate" ratings, and 14 "poor" ratings. Of the 23 structural measures considered, there are six "strong" de minimis justification ratings, seven "moderate" ratings, four "poor" ratings, and six "weak" ratings. These ratings were used in developing implementation phases which is described in the next section.

## **SA WATER DAM SAFETY PROGRAM**

### **Dam Safety Improvement Program (DSIP)**

The DSIP component of SA Water's dam safety program will comprise further engineering evaluations and the implementation of structural and non-structural risk reduction measures. Evaluations will include engineering investigations, including detailed risk assessments, of sufficient depth to achieve a "sign off" level confidence in dam safety evaluations and decision making, and to provide sufficient information for design of structural and non-structural measures.

### **Initial Prioritisation**

An initial priority for implementing the 23 structural risk reduction measures was developed to maximise the rate of estimated risk reduction for the expenditure of capital funds for dam safety improvement. First priority was given to reducing life safety risks until a point of diminishing returns is reached after the first eight measures, and second priority was given to reducing total risk costs (i.e. direct SA Water and third party). The resulting prioritisation is referred to as "the PRA prioritisation".

EWSs were prioritised to maximise the rate of risk reduction by maximising the rate of life safety risk reduction. Risk reduction is shown to be rapid for the three top-ranked EWSs, which coincided with the dams with the highest life safety risks, and relatively small for all other dams.

### **Comparison with Current SA Water Program**

The estimated rate of life safety risk reduction is significantly greater for the PRA prioritisation than for the current SA Water program prioritisation (Figure 3(b)). It is estimated that the proposed DSIP would achieve 98% of the total life loss risk reduction for about 15% of the total capital costs, compared with about 75% of the total capital costs to achieve the same level of risk reduction under the current SA Water prioritisation.

### **Implementation Phases**

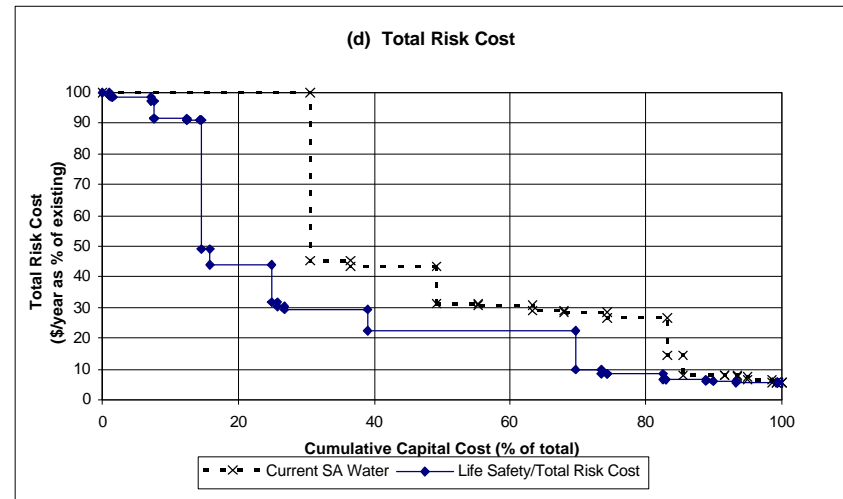
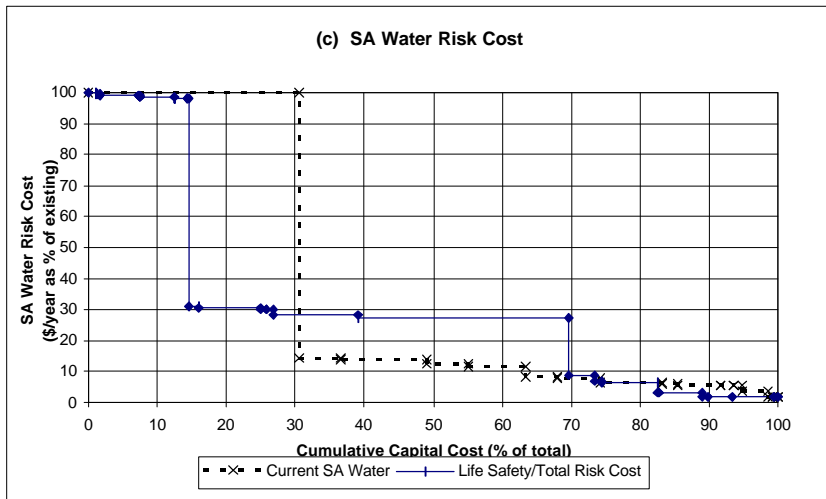
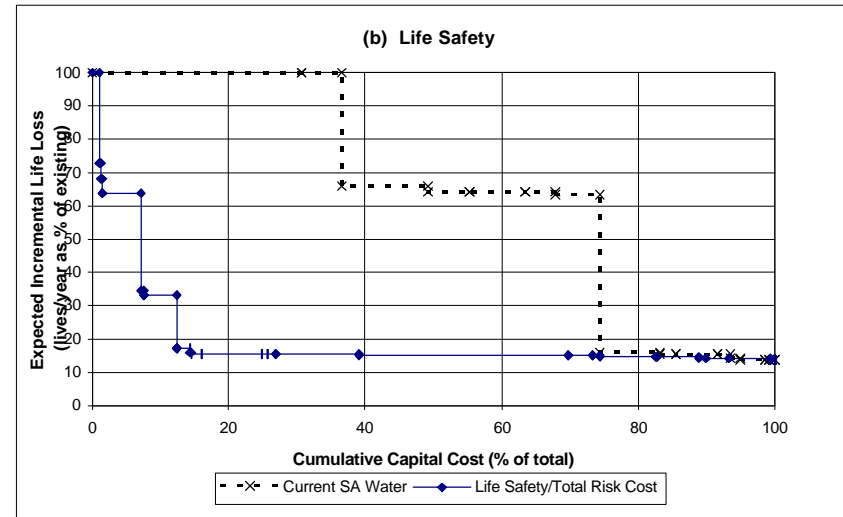
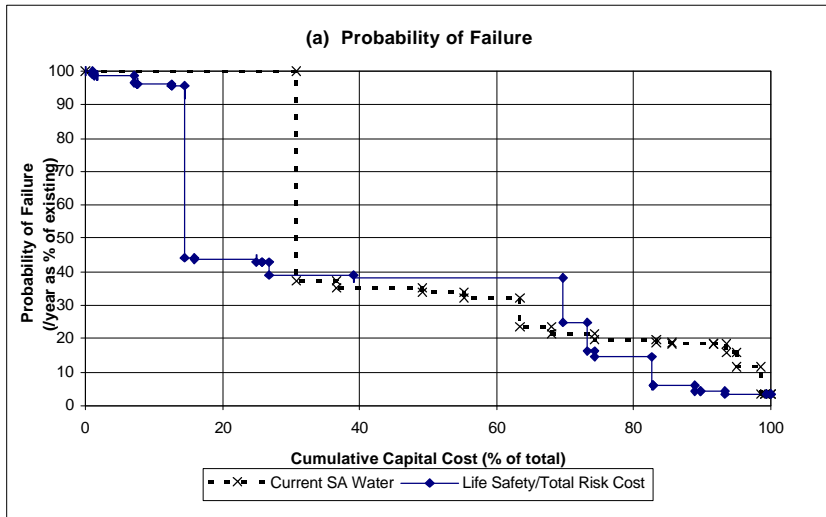
Risk reduction measures were assigned to four implementation phases based on the PRA prioritisation and various risk-based ratings thresholds. SA Water could use these phases as a basis for phasing its Dam Safety Improvement Program. The total capital cost for all structural measures was estimated at more than \$80 million, but SA Water will need to decide whether to implement all the measures in all phases.

The rationale for assigning measures to each phase and the resulting risk reduction is summarised in the following dot points:

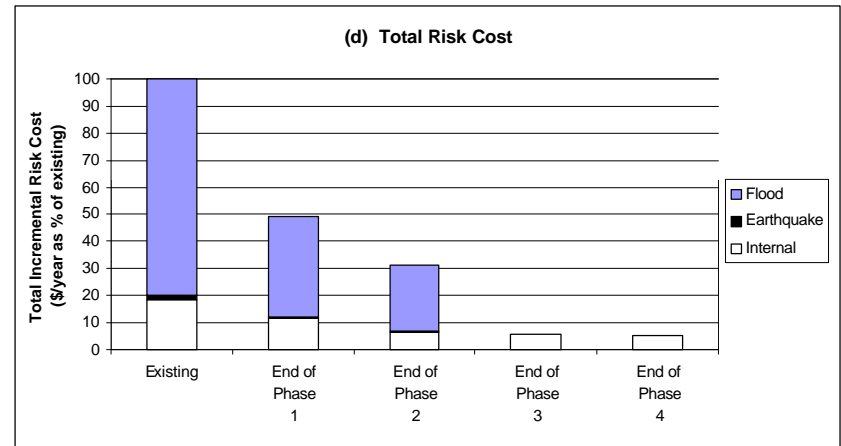
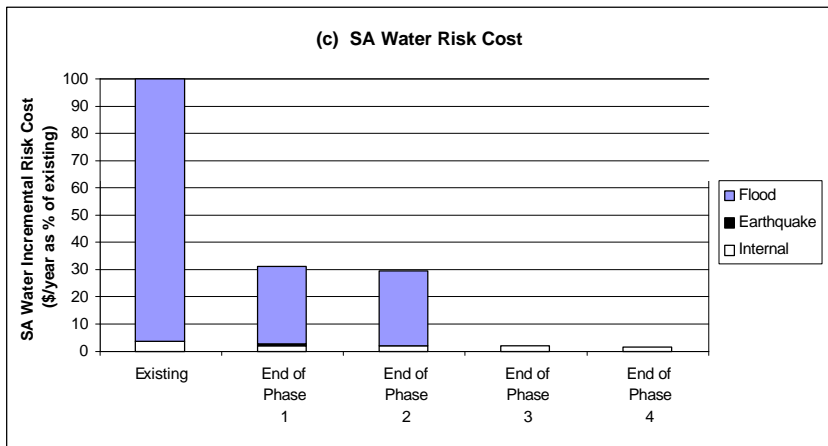
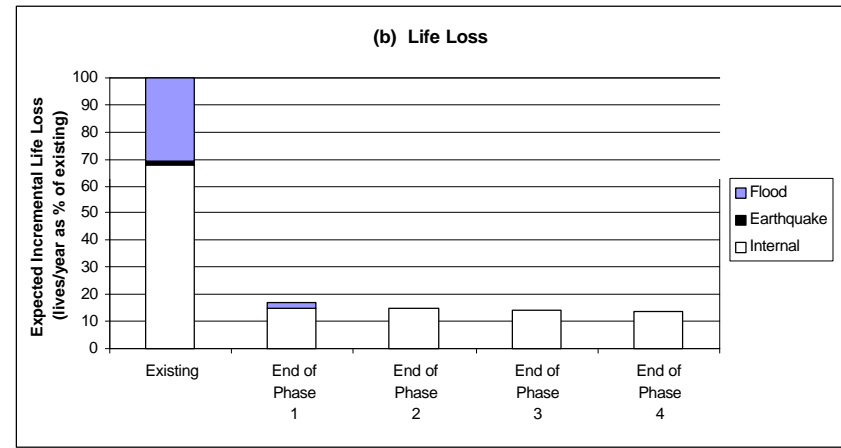
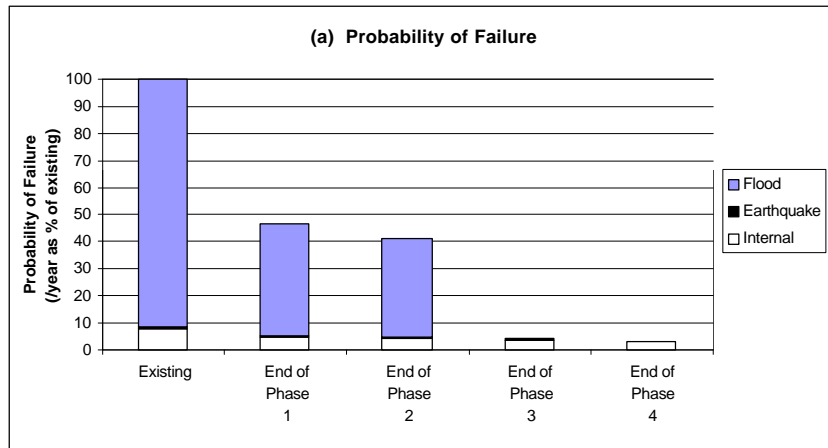
- Phase 1 comprises seven structural measures including all measures with “Very Strong” or “Strong” ALARP justifications, thus ensuring the most rapid initial rate of life safety risk reduction in this phase. It also includes all existing dams which have the USBR Tier 2 “Strong” justification for short term measures. The largest resulting risk reduction is for expected incremental loss of life associated particularly with internal and flood-induced failure modes (Figure 4(b)). Probability of failure (Figure 4(a)) and economic risk cost reductions (Figures 4(c) and 4(d)) are also significant, although mainly associated with flood-induced failure modes.
- Phase 2 comprises six structural measures including all remaining measures which do not appear to meet the ANCOLD societal risk limit criterion, and those with “Moderate” ALARP justifications, and “Strong” de minimis justifications. The principal risk reduction is for third party risk with little change in SA Water risk costs (Figures 4(c) and 4(d)).
- Phase 3 comprises seven structural measures. Three out of seven of these measures address issues which do not appear to meet the ANCOLD societal risk objective criteria. Phase 3 contains all remaining measures with USBR Tier 2 “Increased” justifications. Probability of failure (Figure 4(a)), total economic risk costs (Figure 4(d)) and SA Water risk costs (Figure 4(c)) all decrease significantly due mainly to reduction in flood-induced failure risks.
- Phase 4 comprises all three remaining structural measures. Two of these measures address issues which do not appear to meet the ANCOLD societal risk objective criteria. All types of risk reduction are estimated to be small (Figures 4(a) to 4(d)).

### **SA Water Policies and Procedures**

SA Water's Capital Expenditure Policies and Procedures and related documents were reviewed in the light of the PRA findings and the use of the risk-based approach. Dam safety projects appear to fit under the “risk management” project category, which suggests an important continuing role for both PRA and detailed risk assessments. However it was noted that current procedures do not provide an approach for ranking dam safety projects against commercial projects.



**Figure 3** Comparison of residual risks based on PRA prioritisation and the current SA Water program



**Figure 4** Breakdown of remaining portfolio risk at the end of each implementation phase of structural risk reduction measures

## **APPLICATION OF PRA BY SA WATER**

On the basis of the PRA, a number of recommendations were made so that SA Water can effectively integrate and apply the PRA findings within its existing dam safety program. Key actions that SA Water is, or will be taking, include the following:

- High priority is being given to establishing and implementing a risk based DSIP. The DSIP will comprise: a) further investigations to achieve adequate confidence in all engineering and risk assessments, including the needed basis for design; and b) implementation of all reasonable and practical structural and non-structural measures with the goal of reducing risks to tolerable levels. Emergency preparedness plans and early warning systems will be considered for all dams.
- A Dam Safety Risk Management Policy will be established to provide the necessary corporate framework for implementing the DSIP, including establishing a basis for capital budgeting of dam safety projects.
- The PRA indicated that at some dams there are high life safety risks or a high probability of failure. High priority is being given to evaluating the need for short term measures to reduce risks in these cases.
- Existing dam safety management program activities will be reviewed based on the PRA. Contingency planning assumptions developed by SA Water staff for the PRA will be verified, and if necessary, action will be taken to ensure appropriate contingency measures can be provided.
- Consistent with the baseline nature of the PRA, it is intended to regularly update it as additional information becomes available.
- Based on the PRA, it is not expected that detailed risk assessments will be necessary at all dams but there were a number of dams where the PRA has indicated clear justification for a detailed risk assessment. As a minimum, the initial risk identification step of detailed risk assessment will be applied to all dams.

## **CONCLUSION**

Many useful insights into dam safety issues, which might not otherwise have been obtained, were provided by the PRA process. SA Water now has an overall picture of the current dam safety status of its large dams from both a standards-based perspective and a risk-based perspective. The proposed phased implementation of structural measures and further evaluations is proving useful for prioritising and managing dam safety evaluation and improvement efforts, and importantly, is regarded as a defensible strategy for reduction of risk.

Another significant benefit of conducting the PRA is that it identified a more rapid approach to risk reduction than the existing dam safety program prioritisation, which was based on traditional approaches. By taking a risk-based approach to prioritising dam safety evaluations and improvements, SA Water has obtained information that is useful for integrating dam safety issues into overall business planning, but can still choose whether or not to adopt a standards-based or risk-based approach to establishing safety targets for each risk reduction measure at each dam.

The close partnership between the consultant and SA Water technical staff and the periodic involvement of SA Water executives and the Board contributed to the effective conduct of the PRA and clearly demonstrated that this level of interaction is an essential ingredient in the PRA process if it is to be of maximum value to the owner of a portfolio of dams.

## **ACKNOWLEDGEMENTS**

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