HARVEY WATER

WATER CORPORATION

Review of Dam Safety Program Relating to South West Irrigation Dams

Final Report : August 2003

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GLOSSARY

Term	
ACARP	As low as reasonably possible
AEP	Annual Exceedance Probability
ANCOLD	Australian National Committee on Large Dams
ARR99	Australian Rainfall and Runoff 1999
BWSA	Bulk Water Supply Agreement
CPSLS	Cost per statistical life saved
CSO	Community Service Obligation
DFP	Dairy Farm Performance
DSEP	Dam Safety Emergency Plan
DSU	Dam Safety Upgrades
F-N curve	Frequency Number curve
G-MW	Goulburn-Murray Water
HSC	Health and Safety Commission (UK)
HSE	Health and Safety Executive (UK)
HW	Harvey Water
ICOLD	International Committee on Large Dams
IWSS	Integrated Water Supply System
LOL	Loss of life
PAR	Population at Risk
PLL	Potential loss of life
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
QRA	Quantitative Risk Assessment
SCUP	Separable Construction Upgrade Package
SWIMCO	South West Irrigation Management Co-operative
WACC	Weighted Average Cost of Capital
WAWA	Western Australian Water Authority

REFERENCE COMMITTEE

Chairman

Dr Brian Martin, Co-ordinator of Water Services
Office of Water Regulation

Water Corporation

Lloyd Werner, Manager Pricing and Agreements Branch
Michael Somerford, Supervising Engineer Infrastructure Development

Harvey Water

Dan Norton, Chairman
Geoff Calder, General Manager
Tom Busher, Director
Ian Eckersley, Chairman South West Irrigation Asset Co-operative

CONSULTING TEAM

Peter Jacob	A principal of Marsden Jacob Associates, economist and financial analyst. Peter undertook the financial analyses relating to the South West privatisation and for the first Portfolio Risk Assessment of dam safety in Australia.
Dr John Marsden	A principal of Marsden Jacob Associates, economist with particular expertise in the application of costing and pricing principles to major infrastructure.
Len McDonald	A member of the ANCOLD executive, chair of the working group revising the ANCOLD Guidelines on Risk Assessment, member of the International Commission on Large Dams (ICOLD) and drafting member of ICOLD's committee on risk assessment guidelines, Len has an unparalleled depth and continuous experience on the risk assessment of large dams in Australia and overseas.

Dr Dick Davidson	Dick brings strong geo-technical experience to our team. He has been involved with all types of dams for over twenty-five years. His breadth of experience ranges from building some of the largest earth-rockfill dams in the United States to rehabilitating century-old puddle clay core dams and masonry dams, to stabilising landslides affecting water retention and tailings dams. he has worked extensively for the Corps of Engineers, Bureau of reclamation and many major dam owners throughout the world. dick has special expertise in design, dam safety, risk assessments, dam rehabilitation, slurry wall cutoffs, landslides, seismic behaviour of embankment dams and instrumentation.
Dr Rory Nathan	Dr Nathan is a Senior Principal with Sinclair Knight Merz. He has over 20 years experience in academic and consulting positions, with specialist expertise in the characterisation of hydrologic risk. He was the senior author of the national guidelines on the estimation of large to extreme floods, and was a member of the committee for the development of the current ANCOLD guidelines on acceptable flood capacity of dams. He is the national representative on the ICOLD floods committee, and is a member of the NSW Dams Safety hydrology sub-committee. He maintains an active interest in research at the CRC for Catchment Hydrology and is an Honorary Fellow at the University of Melbourne. He has published over 90 papers in refereed journals and conference proceedings, and has won several national and international awards for his research. Recently he was awarded national Civil Engineer of the Year by the Institution of Engineers.

1 INTRODUCTION

1.1 BACKGROUND & TERMS OF REFERENCE

Water Corporation owns and operates six storages located in the south west of Western Australia that supply the South West Irrigation Management Co-operative (SWIMCO), which trades as Harvey Water (HW), with water for irrigation purposes. Harvey Water then distribute the water to its irrigator members and customers located in three discrete irrigation systems – Waroona, Harvey and Collie.

The supply of water from Water Corporation dams to Harvey Water is subject to a Bulk Water Supply Agreement (BWSA) signed in October 1996 and set of Delivery Operating Rules which are developed and agreed upon by the two parties prior to each annual irrigation season.

As stated in the BWSA, the Bulk Water Entitlement may be varied as to amount and allocations from time to time by:

(a) the Corporation following a direction by the Commission in the exercise of the Commission's statutory powers having regard to water resource availability and such other factors as the Commission is required to take into account under its governing legislation when making allocations of water entitlements; or

(b) agreement between the parties.[1]

Section 5.4 of the BWSA relates to dam safety upgrades and states:

(a) The Bulk Water Price may be increased during the Term or the extended period as a consequence of any increased cost to the Corporation brought about as a result of any Safety Upgrades required to the South West Dams.

(b) The parties expressly agree that there is to be no increase in the Bulk Water Price attributable to the costs incurred by the Corporation in constructing and operating the proposed Harvey Dam or carrying out Safety Upgrades to Harvey Weir.

(c) The parties agree to negotiate in good faith any Bulk Water Price increase referred to in subclause (a), but failing agreement within 3 months of negotiations commencing between the parties, the revised price will be determined by the Minister for Water Resources after consultation with the Coordinator of Water Services and the parties.

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1 Water Corporation and South West Irrigation Management Co-operative Limited, Bulk Water Supply Agreement (1996), p.9.

(d) *The parties acknowledge that in any negotiations under subclause (c), a relevant issue governing any increase in the Bulk Water Price or the magnitude of that increase, will be the extent to which any parties other than Swimco and the Corporation have benefited or will benefit from the relevant Safety Upgrade.*

(e) *The parties further acknowledge that the negotiations contemplated by this subclause may take place at the time the Corporation is committing to the Safety Upgrade and before the date on which the relevant Safety Upgrade is completed, it being agreed that any increase in the Bulk Water Price will not take effect until after the upgrade is completed.*[2]

The BWSA defines Safety Upgrades as any work:

(a) *which, in the reasonable opinion of the Water Corporation, is required in order to maintain the safety of the South West Dams in accordance with the publication entitled "Guidelines on Dam Safety Management 1994" published by the Australian National Committee on Large Dams (ANCOLD) (as the same may be amended from time to time) or as required by any relevant law or regulation; or*

(b) *required by any governmental agency in relation to the safety of South West Dams.*

Under its Statement of Corporate Intent 1999-2000:

the Water Corporation was formed under the Water Corporation Act 1995 to fulfil the following principal functions:

- *To acquire, store, treat, distribute, market and otherwise supply water for any purpose;*
- *To collect, store, treat, market and dispose of wastewater and surplus water.*

In performing these functions the Corporation must:

- *Act in accordance with prudent commercial principles; and*
- *Endeavour to make a profit, consistently with maximising its long-term value.*

In Appendix 3 of the Statement of Corporate Intent 1999-2000, under a description of Dam Safety, as one of eight Community Service Obligation (CSO) programs, it states the following:

2 Water Corporation and South West Irrigation Management Co-operative Limited, Bulk Water Supply Agreement (1996), p.11.

> *The Water Corporation has a duty of care to maintain dams to current community standards. Community standards in this case have been based on guidelines produced by the Australian National Committee on Large Dams (ANCOLD). These guidelines are accepted practice in most major dam owning organisation Australia. Following these guidelines, those Water Corporation dams which do not meet ANCOLD standards are being upgraded.*[3]

Since the signing of the BWSA in 1996, Water Corporation, as required by ANCOLD Guidelines, has undertaken dam safety reviews on the six irrigation dams in the south west of the State with the new dam, Harvey Dam, being constructed replacing the former Weir. These dam safety reviews identified deficiencies with all six dams and recommended significant remedial works be undertaken. Based on these reviews, portfolio risk assessment was undertaken to prioritise the remedial works and a program of works was developed.

This program of works is currently costed at around $102 million and could be up to 50% higher. The 2002 estimates are therefore a multiple of six times above the $17 million suggested at the time of negotiating the BWSA. The imposition of $102 million on the capital costs of bulk water would increase the average Bulk Water Price to Harvey Water by around $57 per ML delivered – an seventeen-fold increase over the current price.

For these several reasons Water Corporation and Harvey Water commissioned Marsden Jacob Associates to undertake an independent and comprehensive assessment of these issues.

The scope of work required to be addressed by this independent study includes:

- an assessment of the relevance of the interpretation and application of ANCOLD 1994 guidelines to irrigation dams in other parts of Australia to this Dam Safety Program;
- evaluation of the risk assessment processes used and the risk levels adopted;
- an assessment of the proposed remedial works program to upgrade the safety of South West (irrigation) dams to comply with the Bulk Water Supply Agreement;
- determination if provisions of the Bulk Water Supply Agreement, in relation to the dam safety program, have been applied;
- discussion of the long-term financial commitment being sought under the Bulk Water Agreement in relation to the short-term (5 year) nature of the SWIMCO licence and advise on appropriate arrangements for implementation and ongoing management; and

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[3] Water Corporation (2000), Review and Update of Dam Safety Portfolio Risk Assessment, RAC Engineers & Economists, Utah USA, February, Section 4.3.1.

- provision of recommendations for apportioning the costs of dam safety works between beneficiaries.

The assessment is guided by a Steering Committee comprising two HW and two Water Corporation members, chaired by the Office of Water Regulation.

1.2 DESCRIPTION OF SYSTEM

Harvey Water owns and manages three separate irrigation systems – Waroona, Harvey and Collie – located on the coastal plain in the south west of Western Australia. As noted, water for the three irrigation schemes is sourced from eight storages and weirs as summarised below.

Under the BWSA, Harvey Water holds a Bulk Water entitlement of 153,460 ML which will be supplied by the Corporation to Harvey Water at five measuring points according to the allocation set out in Table 1.1.

Table 1.1 : Bulk Entitlement Delivery Points and Allocation

Delivery Point	Allocation (ML)		Average Deliveries
Waroona System			
Drakesbrook	9,700	17,460	7,893
Samson Brook	7,760		
Harvey System			
Logue Brook	11,000	68,000	43,716
Harvey Dam	57,000		
Collie System			
Burekup Weir	68,000		43,716
Total	**153,460**		**95,325**

Waroona Irrigation Scheme

The Waroona Scheme is supplied from two principal sources – Waroona Dam and Samson Brook Dam. Waroona Dam, with a total capacity of 15 GL and an average annual yield of around 7.9 GL accounts for around 44% of the total scheme supply.

Releases from Waroona Dam are undertaken normally by Water Corporation to ensure that Drakesbrook Dam (capacity of 2.2 GL and yield of around 1.8 GL) located downstream is kept at optimum operating level of 71 metres AHD. Water released from Waroona Dam takes approximately three hours to reach Drakesbrook Dam via a natural water course.

The outlet on Drakesbrook Dam which is controlled by SCADA by the Water Controller for Harvey Water, is the main measuring point from which water used for irrigation is measured and billed. All losses downstream of the outlet are attributed to Harvey Water.

Samson Brook Dam with a capacity of 8 GL, is the other source of supply to the Waroona system, as well as for industry and the Waroona town water supply. Similar to Drakesbrook Dam, Harvey Water controls the releases from Samson Dam using SCADA to match orders from its customers. Water from the outlet flows via the natural water course which conveys water to the channel irrigation system. The outlet is the principal measuring point for irrigation water.

Both Waroona and Drakesbrook have significant tourism and recreational activities associated with the storages. Water Corporation has applied for a licence to take water to Perth from Samson Brook and, if successful, plan to construct a pipehead dam and treatment plant below the dam and to connect with the Stirling Trunk Main to Perth. This would allow them to take overflow water to Perth during late winter. Given this, it is likely that recreation would be prohibited on Samson Brook Dam.

Harvey Water has well actioned plans to construct a pipeline from Drakesbrook Dam and to provide a piped supply to at least some of the Waroona system. Harvey Water has also constructed a pipeline to transfer up to 4 GL per year between the Waroona and Harvey systems.

Harvey Irrigation Scheme

The Harvey Irrigation Scheme is located between the Waroona System to the north and the Collie System to the south. The irrigation scheme is supplied from the outlet of the new Harvey Dam which is located downstream of the Stirling Dam. The outlet pipeline, which is connected to the main dam outlet, has three SCADA controlled off-takes that are operated by Harvey Water’s Water Controller and supply water into the open channel system.

Releases from Stirling Dam are undertaken normally by Water Corporation to ensure that Harvey Dam is kept at an optimum operating level of 64 metres AHD. It takes approximately 12 hours for water released from Stirling Dam to reach Harvey Dam.

The Harvey and Stirling Dams are operated as a capacity sharing arrangement whereby Harvey Water has rights to virtually all the water in Harvey Dam (with the exception of a small volume allocated for environmental/cultural purposes). In terms of the Stirling Dam, Harvey Water has rights to 40% of the inflows and Water Corporation 60% excluding any water which Water Corporation pumps into Stirling from the Harris Dam.

Water Corporation has applied for a licence and permission to construct a pipehead dam on Wokalup Creek where winter flows would be transferred to Harvey Dam for irrigation (Harvey Water) use. In turn, this would make up to 10 GL available from

Stirling Dam for use in the Integrated Water Supply Scheme. At 10 GL this would reduce Harvey Water's share of Stirling Dam from 40% to 20%.

The other supply source for the Harvey Scheme is Logue Brook Dam which has a capacity of 24 GL. A feature of the Logue Brook Dam is its small catchment and infrequency of spilling and therefore it rarely provides its licensed allocation.

The Water Controller schedules delivery and indicates the release from the dam using the SCADA Control System. A V notch weir with an ultrasonic flow meter, located just downstream of the outlet, is used to record the flow into the irrigation system via a natural water course.

Water skiing is a popular activity on Logue Brook.

Collie Irrigation Scheme

The Collie Irrigation Scheme is supplied with water from the Wellington Dam which has a capacity of 186 GL and an average annual yield of around 100 GL. Harvey Water has a licence to take 68 GL from Wellington Dam, with 8 GL being allocated to the environment with the remaining 24 GL unallocated but reserved for industry. Water Corporation has applied for a licence to take 15 GL to the Integrated Water Supply System (IWSS) and 5 GL for Western Power.

Releases from Wellington Dam flow via a natural watercourse to Burekup Weir from where level sensors activate releases to the irrigation system. The outlet at Burekup Weir is Harvey Water's main measuring point and all losses upstream of that point are attributable to Water Corporation.

Given that Burekup Weir when full can only accommodate 2 to 3 hours of supply at maximum flow, it is critical that extraction rates from the weir match releases from Wellington Dam. With a 12 hour delivery time from Wellington and only 3 hours of storage, maintaining optimum delivery levels is difficult and requires constant alteration by Harvey Water's Water Controllers, who initiate the releases from Wellington Dam.

In addition to irrigation releases, water is also released for environmental and town water supply purposes. Further, Water Corporation manages scour releases outside the irrigation season in order to manage the salinity of water released for irrigation. Logging within the Wellington Catchment has lead to a substantial increase in the salinity of the run-off water entering Wellington Dam. This saline water gravitates to the lower depths and can be partially drawn off through releases via the main scour valve.

1.3 CONDUCT OF REVIEW

The study was conducted jointly for Harvey Water and Water Corporation under the guidance of a Steering Committee. The Steering Committee was chaired by Dr Brian Martin, Co-ordinator of the Office of Water Regulation, and comprised members of Harvey Water and two representatives from Water Corporation.

The consultant team comprised two principals from Marsden Jacob Associates, Dr John Marsden and Peter Jacob, and one each from URS Australia Pty Ltd – Dr Dick Davidson (geo-technical expertise), and SKM Pty Ltd – Dr Rory Nathan (hydrological expertise). An additional advisor to the consultant team was Mr Len McDonald, currently Assistant Secretary of ANCOLD who provided insights to current and developing ANCOLD guidelines, thinking and practice.

An inception visit was made by the Consultant Team, comprising two principals from Marsden Jacob Associates and one each from URS and Sinclair Knight Merz, from 11 to 13 September 2002. During this visit an inspection of all dams was undertaken and an Inception Meeting held with the Steering Committee and other representatives from both Water Corporation and Harvey Water.

A second Steering Committee meeting with additional representatives from Harvey Water was held on 11 and 12 November 2002 during which presentations were made on the technical review matters and preliminary observations on cost sharing issues.

A third meeting of the Steering Committee was held on the 16 and 17 December to discuss the draft report. Further meetings were held with the Steering Committee to obtain detailed feedback on the draft report and to finalise this report.

Two Consultant Team workshops were held during the course of the project. In addition, Doctors Nathan and Davidson had the opportunity to discuss their observations and understandings with two of the Corporation's consultants, Mr Bob Wark and Mr John Ruprecht.

2 RELEVANCE OF ANCOLD & OTHER CRITERIA

The purpose of this chapter is to set out the essence of the framework of guidelines and default standards developed by ANCOLD. In addressing the issues of the relevance of the interpretation of the ANCOLD guideline to the Dam Safety Program for the six South West Dams, we set out below:

- the historical and legislative context for the development of dam safety guidelines;
- the major guidelines and standards developed to date by ANCOLD;
- the concepts and guidelines for the limits of tolerability for societal and individual risk;
- the As Low As Reasonably Possible (ALARP) criteria; and
- the practical integration of the standards on the limits of tolerability and the ALARP criteria.

2.1 HISTORICAL & LEGISLATIVE CONTEXT

Traditionally dam safety was managed by very conservative and prudent design rules. With the failure of the Titon Dam in 1976, the US enacted federal legislation requiring a more formal and active approach to dam management and safety. US standards and guidelines developed rapidly in the next decade.

By the mid 1980s the focus on dam safety upgrades had widened with the formation on the Australian National Committee on Large Dams (ANCOLD) and the International Committee on Large Dams (ICOLD).

Much of the impetus to adopt a risk-based dam safety practice came from the corporatisation in the 1990s of the state government organisations charged with managing dam headworks infrastructure. The newly formed Boards governing these dam-owning corporations needed a consistent and robust process to assess the risk posed by this aging infrastructure.

In Australia, the NSW dam safety committee moved quickly and early to establish risk standards, particularly because many of the State’s dams were owned and managed by local or county governments with little relevant expertise. NSW and Qld have enacted legislation to formalise their approaches to dam safety.

In contrast, Victoria, South Australia and Western Australia have not established specific dam safety legislation with the result that the ANCOLD framework of guidelines and risk standards, as the national community standard, sets the applicable standards and framework for those states.

In the past, dams had been designed and assessed based on deterministic standards established by the national and international dams community. However, over the years design loadings, methods and standards have changed reflecting the advances in the knowledge and technology of the profession. This has left much of dam infrastructure deficient in relation to these modern standards. It would be impossible both from resource and financial perspective to bring these dams up to the modern standard in a short timeframe. Therefore, it was essential to identify the priorities for dam safety upgrades to utilise the limited resources available to dam owners as effectively as possible, exercising due diligence in the process. Using risk as the discriminator in setting these priorities was the right tool for the job.

The fundamental premise of the risk-based dam safety practice is that various dam failure modes can be compared with tolerability criteria based on their quantified risk. If a consistent process is used across the entire register of failure modes, then the failure modes can be ranked. If a consistent process is used across the entire inventory of dams, then the total risk for each dam can also be ranked and prioritised.

The methods for risk analysis embodied in ANCOLD are consistent with international practice, including in the areas of health and safety but the risk standards themselves are not integrated or necessarily consistent with explicit and implicit standards adopted elsewhere.

2.2 MAJOR ANCOLD GUIDELINES AND DEFAULT STANDARDS

Relevant ANCOLD Guidelines for this review include:

- Guidelines on Selection of Acceptable Flood Capacity for Dams;
- Guidelines for Design of Dams for Earthquake;
- Guidelines on other physical aspects such as Design Criteria for Concrete Gravity Dams, Strengthening and Raising Concrete Gravity Dams; and
- Dam Safety Management.

In addition, work on, and consideration of, new guidelines on the management of risk for dams is well advanced.

2.3 LIMITS OF TOLERABILITY

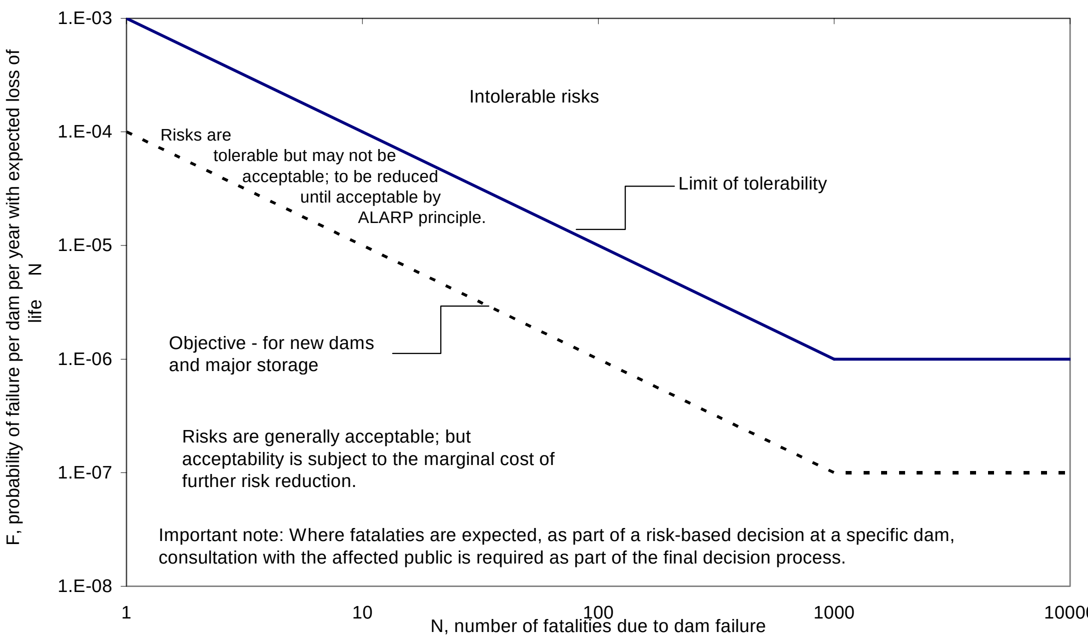
A key feature of the ANCOLD Guidelines is the setting of acceptable or tolerable levels of risk. For flood risk the level of tolerability for loss of life decreases as the estimated number of lives lost increases and should be no more than 1 in 1 million i.e., 10^{-6}. The tolerability criterion is not, however, the only relevant criterion.

ANCOLD (1998a) and (2001) established very useful tolerability (or societal) risk criteria, which reflected society's aversion to events which have the potential to cause large loss of life (LOL). Figure 2.1 shows the currently agreed limits of tolerability while Figure 2.2 indicates the shift in thinking as indicated by the more recent draft risk criteria.

Risks which exceed this tolerability criterion must be reduced. Risks that fall below this criterion should be reduced As Low As Reasonably Practicable (the ALARP principle). The ALARP principle states that risk reduction measures should be implemented until no further risk reduction is possible without very significant capital investment or other resource expenditure that would be grossly disproportionate to the amount of risk reduction achieved. This reasonableness test is an important tool is developing a staged approach to risk reduction that is often necessary to expend diligently the very limited resources available to most dam owners in addressing dam safety deficiencies.[4]

Eventually, the dams should be brought up to the modern standard or a conscious risk-based decision is made in consultation with stakeholders to set the standard for the dam. For example, fallback flood capacity guidelines have been set by ANCOLD (2000) based on downstream hazard classification. The lower the hazard, the smaller the required flood capacity. In some cases with extreme hazard consequences, the agreed design standard may actually exceed the published standard to achieve the desired level of risk exposure and conservatism.

Figure 2.1 : ANCOLD Limits of Tolerability : Currently Agreed

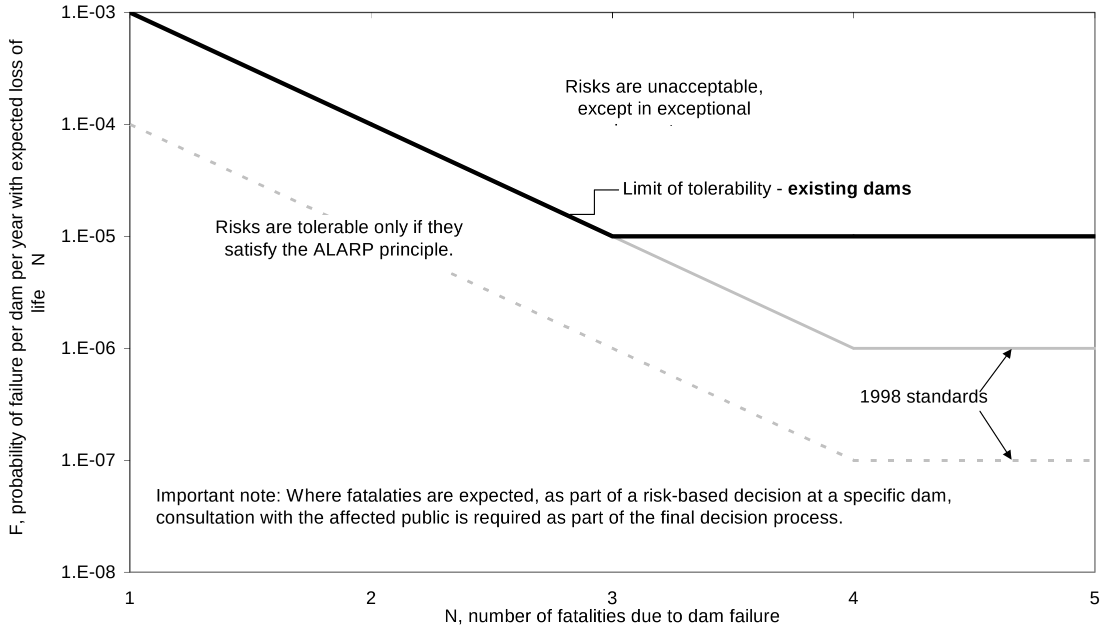


Source: ANCOLD (1998a)

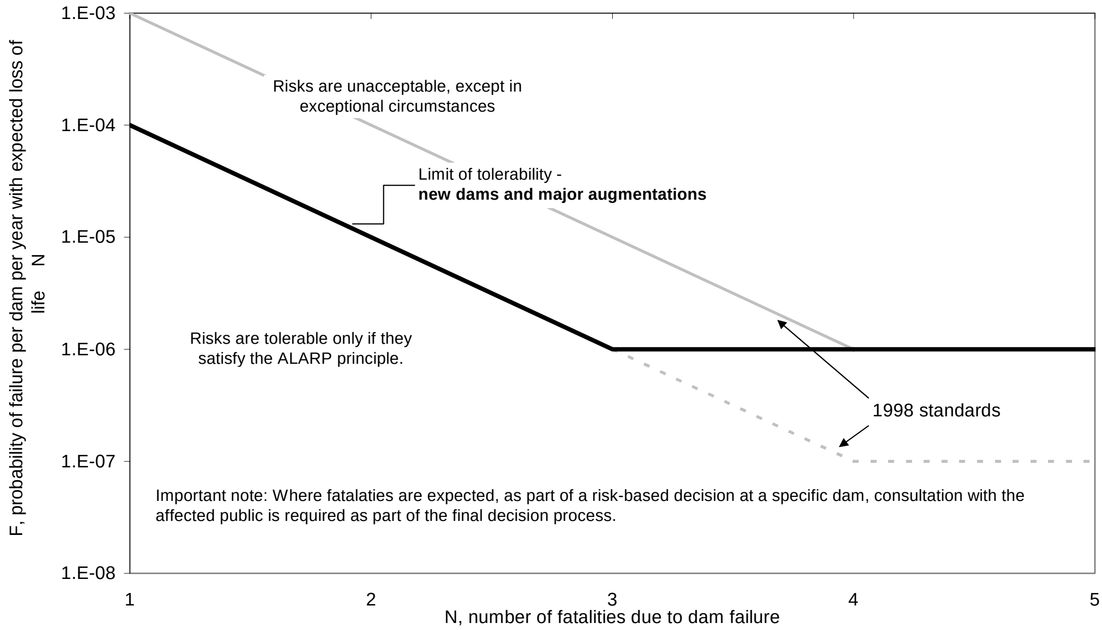
4 Risks falling below the ALARP standard are effectively accepted as self-insurance.

Figure 2.2 : ANCOLD Limits of Tolerability – Draft 2001

(a) Existing Dams



(b) New Dams and Major Augmentations



Source: ANCOLD 2001

2.4 THE ALARP CRITERION

The "As Low As Reasonably Possible" (ALARP) criterion states that risks are acceptable only if reasonable practical measures have been taken to reduce risks.[5] As noted in Bowles *et al* (2001) :

> *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 these further. The cost of improving life safety* [i.e., cost-per-statistical life- saved] *can be used to assess the degree of ALARP justification for a risk reduction measure."*[6]

ALARP is therefore a criteria reflecting the trade-off between cost and risk reduction rather than a pure risk standards based approach. As such, the relationship between ALARP on the one hand and (prescribed, implied or default) standards on the other hand varies from situation to situation, risk to risk.

In some cases, the ALARP criterion will imply a greater reduction in risk than does adoption of a standards approach. As noted by Bowles *et al* (2001) where dams are closely proximate to large downstream populations at risk, risk-based criteria may be more difficult to meet than standards. In other cases, consideration of the ALARP criteria will suggest less expenditure of effort than required by adoption of the applicable standard.

Similarly, the South Australian Water Corporation noted

> *The proposed works constitute part of the Corporation's dam safety program to reduce the risks associated with its large water supply dams. The risks are being reduced to a level that is as low as reasonably practicable and in accordance with modern international benchmarks.* [7]

Thus, contrary to the common – but incorrect – diagrammatic representation, ALARP is not a uniform parallel shift to the left of the line showing the ANCOLD determined limits of tolerability (as exemplified by Figure 2.1a).

2.5 INTEGRATION OF STANDARDS/LIMITS & ALARP

In the case where the ALARP criterion suggests that it is not worthwhile to move to standard, the presence of the risk standard may still force the business or utility to move toward the standard even though in terms of the benefits and costs of doing so it may be unreasonable to do so. This is shown in the top panel of Figure 2.2.

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5 IAEA 1992, quoted in Bowles (2001).

6 Bowles *et al* (1998), quoted in Bowles (2001)

7 South Australian Water Corporation (2000) *Hope Valley Reservoir Rehabilitation Project*, Report to Public Works Committee, July, p. 1.

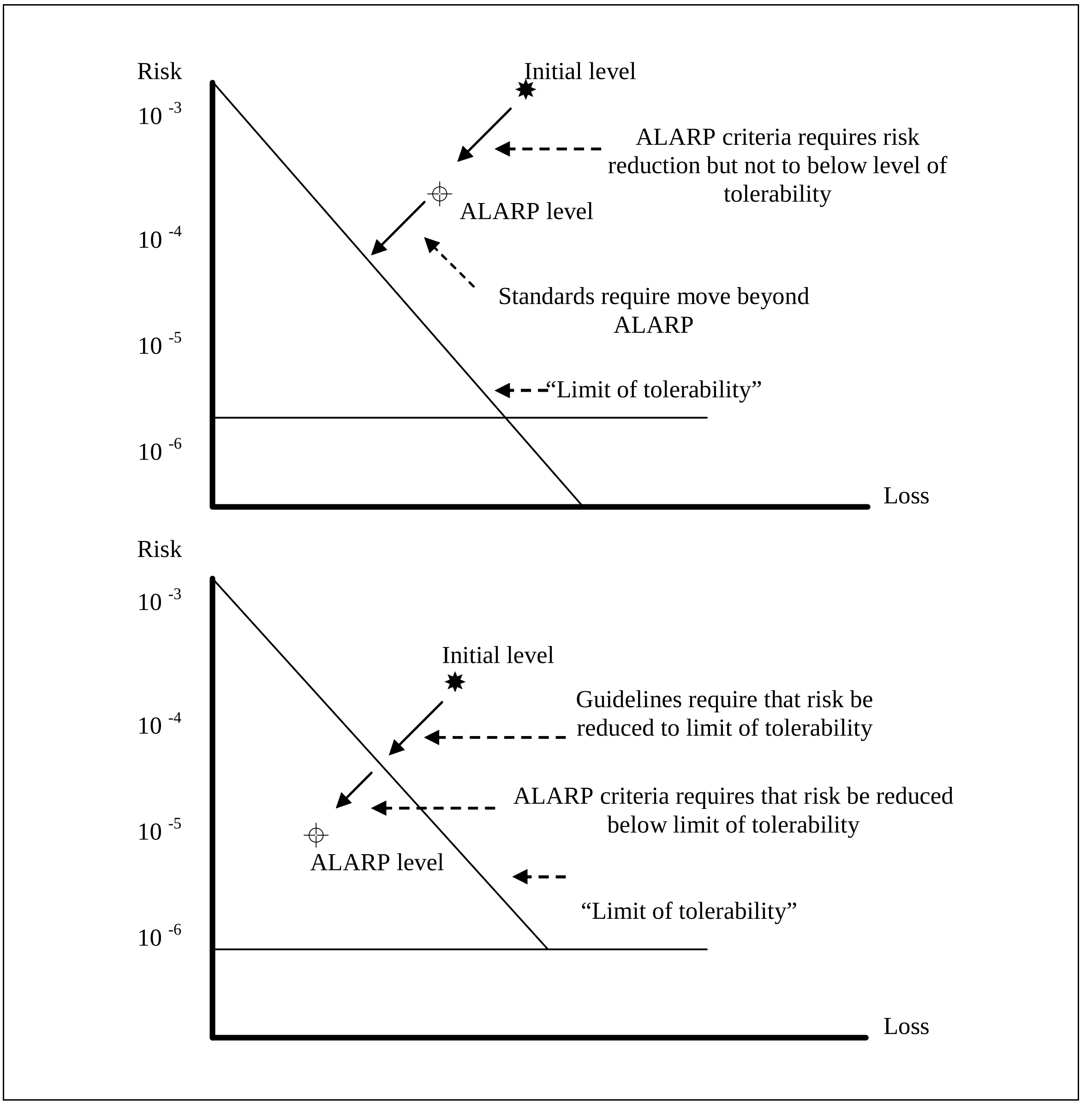
On the other hand, where the risk has been reduced to the limit of tolerability, the utility can not rest there if the ALARP criterion indicates that further reductions in risk can be achieved cost effectively. This case is shown in the bottom panel of Figure 2.2.

Thus, there is a significant potential asymmetry where risk standards are prescriptive rather than guidelines and/or the courts and boards of directors interpret guidelines and default parameters as the national standard thus forcing entities adopting a risk-based approach to justify their decisions not to adopt the "community" standard.

In the absence of explicit legislation and regulations covering dam safety, this asymmetric situation applies in Western Australia, South Australia and Victoria.

To remove this asymmetry and the higher levels of expenditures on dam safety upgrades that it drives would require legislation to set a state policy on acceptable risk.

Chart 2.2 : Limits of Tolerability & the ALARP Criterion



3 BEST PRACTICE IN DAM SAFETY REVIEWS

3.1 BEST PRACTICE AS OBSERVED IN OTHER JURISDICTIONS

Background

Australian dam owners and consultants have established a world-leading risk-based approach to dam safety, which has been documented in a series of Australian Committee on Large Dams (ANCOLD) publications[8]. Related risk-based criteria have been developed for earthquakes and floods in other ANCOLD Guidelines[9]. Risk-based dam safety approaches and precedent have been the subject of technical sessions in the past four ANCOLD Annual Conferences on Dams. Although the process has been undergoing a rapid stage of development, it is now well established throughout Australia, with most dam owners, such as Water Corporation in Western Australia, having incorporated it into their dam safety program.

Australian Risk-Based Dam Safety Programs

The first efforts in Australia with risk-based dam safety programs were typically semi-quantitative or portfolio level risk assessments of an owner dam inventory. Examples include the Victorian Business Risk Assessment process[10] and the SA Water portfolio risk assessment[11] (PRA). The Victorian effort provided a useful prioritisation of dams for design review and remedial works. The PRA for SA Water bravely identified a suite of remedial works at each of its dams, indicated quantum of cost and risk reduction prior to implementing any design reviews. The highest priority remedial works project[12] was started soon after with design review investigations followed by design and implementation of the remedial works. These remedial works were recently completed.

Detailed risk assessments were also being implemented for specific projects such as Hume Dam[13] and Lake Eucumbene[14] in NSW, and Lake Eppalock[15] and Wartook

8 ANCOLD (1994) *Guidelines on Risk Assessment*, January; ANCOLD (1998a**)** *ANCOLD Guidelines on Risk Assessment, Position Paper on Revised Criteria for Acceptable Risk to Life,* August; and ANCOLD (2001) *Guidelines on Risk Assessment,* Draft, July.

9 ANCOLD (1998b**)** *Guidelines for Design of Dams For Earthquake*, August; and ANCOLD (2000**)** *Guidelines on Selection of Acceptable Flood Capacity for Dams*, March.

10 Watson, D and J Adem (1998) *Risk Assessment of Dams – Future Directions for Victoria*, ANCOLD Conference on Dams, Sydney, September

11 Bowles, D, A Parsons, L Anderson & T Glover (1998) *Portfolio Risk Assessment of SA Water's Large Dams*, ANCOLD Conference on Dams, Sydney, September

12 Bell, G, G Gosden & A Parsons (2001) *Safety Investigation and Remedial Works of Hope Valley Dam,* NZSOLD / ANCOLD Conference on Dams, Auckland NZ, November

13 McDonald, L and Wan, C (1998) *Risk Assessment for Hume Dam – Lessons from Estimating the Chance of Failure*, ANCOLD Conference on Dams, Sydney, September

14 Bell, G, R Fell & M Foster (2001) *Risk and standards Based Assessment of Internal Erosion and Piping Failure – A Convergence of Approaches*, NZSOLD / ANCOLD Conference on Dams, Auckland NZ, November

15 Woodward-Clyde (1999) *Risk Assessment Lake Eppalock*, Report prepared for Goulburn-Murray Water, May

Dam[16] in Victoria. These efforts were characterised by failure modes and effects analysis, creation of detailed event trees for each failure mode, statistical and expert panel assessment of component probabilities, and comparison with ANCOLD societal risk guidelines. For Hume Dam, thousands of event trees were prepared over the two-year study period, which was subsequently repeated in an expert panel format by a David Bowles-led team for both Hume and Dartmouth Dams. In the case of Hume Dam, one objective was to evaluate whether a detailed assessment of the risk could influence the standard to which the dam would need to be upgraded. However, since the downstream hazard from dam failure was extreme, this was an unlikely outcome. For the Eucumbene embankment, convincing laboratory continuing erosion testing and detailed event trees provided a strong basis to accept the very low piping risk, even though modern filter criteria were not fully satisfied. For Eppalock and Wartook, these detailed risk assessments provided a basis to judge the urgency of works and the opportunity for staging the works over several years. These detailed risk assessments also led to some useful improvements in various flood[17] and piping[18] risk estimation procedures.

Portfolio risk assessments[19] became very popular in the following years being implemented by DLWC,[20] Coliban Water, NQ Water, Southern Rural Water, South Gippsland Water, Central Highlands Water, Hydro Tasmania, SEQWB, Snowy Hydro and Water Corporation. These efforts became more quantitative than their predecessors but did not always use independent expert panels nor did they involve stakeholders. Their main function was to prioritise dams for design reviews, investigations, and risk reduction measures and works programs. However, the PRA process has been criticised when it is used to provide definitive works budgets prior to design reviews being completed. In many cases the actual costs come in much higher than originally budgeted in the PRA and the reliability of the entire dam safety upgrade process was called into question. Boards and senior management often do not fully appreciate the large uncertainty band placed on these cost estimates.

In the past two years, Goulburn-Murray Water (G-MW) has embanked upon the most advanced program of risk-based dam safety management in Australia. G-MW is the largest of the corporatised bodies formed from the Victorian Rural Water Corporation and as such has responsibility for 13 state-owned major dams and four Murray-Darling Basin storages. The evolution of the G-MW dam safety program over the past five

16 Westmore, R and Cummins, P (1998) "Risk Based Approach to Wartook Reservoir Rehabilitation," ANCOLD Conference on Dams, Sydney, September

17 Hill, P, R Nathan, E Weinmann, J Green (1999) "Improved Estimates of Hydrologic Risk – Impacts of the New Flood Guidelines," ANCOLD Conference on Dams, Jindabyne, November.

18 Foster, M, Fell, r., Davidson, R., Wan, C., (2001) "Estimation of the Probability of Failure of embankment Dams by Internal Erosion and Piping Using Event Tree Methods," NZSOLD / ANCOLD Conference on Dams, Auckland NZ, November.

19 Bowles, D (2000) "Advances in the Practice and Use of Portfolio Risk Assessment" ANCOLD Conference on Dams, Cairns, October.

20 Cummins, P, P Darling, P Heinrichs, J Sukkar (2001) "The Use of Portfolio Risk Assessment in the Development of a Dam Safety Program for Council-Owned Dams in NSW," NZSOLD / ANCOLD Conference on Dams, Auckland NZ, November.

years is documented in a series of papers.[21] The risk basis for the dam improvement program has developed from the Churchill Fellowship work of Shane McGrath[22] into the current Strategic Risk Assessment process for the thirteen dams.[23] A copy of this paper is provided in Appendix B.

In summary, the Strategic Risk Assessment process was divided into two elements:

- individual risk assessments of the five priority dams for which design reviews were complete to guide formulation of risk reduction strategy; and
- portfolio risk assessment to prioritise design reviews for the remaining eight dams.

The overall risk assessment approach was to develop a quantitative understanding of the key contributors to risk at each of the dams and to then prioritise the risk events across the entire range of dams so that a risk-based risk management strategy could be developed. Specifically, the process for the priority dams risk assessment was as follows:

- **Engineering Assessment** of information including detailed design reviews for each dam by an expert Engineering Panel to apply event tree analysis to identify the probability of each potential type of failure.
- **Consequence Assessment**. A broad range of potential consequences (social, environmental, business) was evaluated by an expert Consequences Panel with respect to loss of life and financial cost.
- **Risk Profile**. A measure of risk was derived for each failure type and for each dam; and risk profiles were generated that show the total risk presented by each major dam and the risk for all dam failure types, ranked in order of decreasing risk.
- **Risk Management Strategy**. The event trees and risk profiles were used to develop a prioritised list of risk reduction actions (a risk management strategy) for all failure types applicable to the priority dams. The risk reduction benefits and the costs of achieving the benefits were compared and used to develop a schedule of risk management actions.
- **Stakeholder Reference Panel**. The dams risk assessment process was reviewed throughout its progress by a G-MW Board-appointed Stakeholder Reference Panel. The panel included a broad range of local authorities and interest groups.

The process for the G-MW portfolio risk assessment was similar but with significantly less information on the remaining eight dams available for engineering assessment.

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[21] Howley, I, G Smith, D Stewart (1998) *From Dam Owners to Water Managers*, ANCOLD – NZSOLD Conference on Dams, Sydney, September and McGrath, S, M Cowan (1999) *A Dam Improvement Program – An Owners Perspective*, ANCOLD Conference on Dams, Jindabyne, November

[22] McGrath, S (2000) "Risk Assessment and Dams – Is It Safe," ANCOLD Conference on Dams, Cairns, October.

[23] Davidson, R, S McGrath, A Bowden, A Reynolds (2002) "Strategic Risk Assessment For Thirteen Victorian Dams," ANCOLD Conference on Dams, Adelaide, October.

Consequence assessments were limited to computation of the population at risk (PAR) and the loss of life (LOL) from limited dam break modelling, and then using similar catchment data from the priority dams to provide an approximate quantum of financial cost risk. Remedial works estimates were based on similar works conducted on comparable dams. G-MW was very careful not to use the portfolio risk assessment prioritised risks and remedial works estimates with the same confidence as the priority dams detailed risk assessment because of the limited information used in developing the portfolio risk levels and estimates.

Benchmarking Australian Best Practice

Best practice in Australian dam safety management has rapidly evolved over the past five years. Today it would be comprised of the following elements:

- portfolio risk assessment to prioritise further investigations and reviews based on business risk and societal risk (includes preliminary risk assessment and consequence assessment, and may include very preliminary remedial works cost estimate);
- failure modes and effects analysis to identify potential dam safety issues (this can be conducted as part of the portfolio risk assessment or design review exercise);
- design reviews of prioritised dams including detailed investigations and analyses of hydrologic, hydraulic, structural, geotechnical and mechanical issues in comparison with deterministic standards. Independent external expert review is important at this stage and should continue through the rest of the process;
- detailed risk assessment and consequence assessment (may be limited to lives risk or may include business financial risk) to confirm risk situation and risk ranking;
- conceptual design of risk reduction works to either achieve interim risk or deterministic standards;
- development of risk reduction strategy of prioritised risk reduction works to progressively achieve risk targets and eventually deterministic standards;
- review by a stakeholder reference panel and presentation to Board of Directors for approval;
- complete detailed design and implementation of approved risk reduction works and initiate non-structural measures; and
- update risk assessment and risk reduction strategy as works are implemented, risk models can be useful in evaluating interim risk and construction risk.

Benchmarking provides a useful check on which elements of the current Australian best practice are being utilised by various dam owners. A comparison of Water Corporation’s dam safety practice with similar dam owners around Australia is illustrated in Table 3.1. The level to which any owner implements these practices is determined based on Board priority, budget and funding sources, and available resources.

In most cases, due diligence exercises for corporatisation identified dam safety risk and funding was set aside for future expenditures. An example was DNRE in Victoria, which made seed funding available to be matched by irrigators to "kick start" the process.

In the past, experienced staff resources were maintained within each state agency, but after corporatisation these resources are now scattered throughout the corporatised bodies and in engineering consultancies. Therefore, a number of owners have established competitive engineering consultant panels to make these resources readily available. Other owners have tendered out blocks of work or individual assignments for their highest risk dams. Other owners have done most of this work in-house. There is a significant advantage in using in-house resources that already know the dams, but there is also an inherent risk that those with a vested interest or prior responsibility for the problems will not provide a truly objective assessment. We advocate a mix of the established historical expertise with new innovative and independent experience to provide the most effective contribution to a successful dam safety program.

Water Corporation generally compares quite favourably with other major dam owners around Australia, having utilised most of the current suite of dam safety tools and processes except for detailed risk assessment and stakeholder reference panels. The best means to assess Water Corporation's process is to examine that used for Waroona in detail.

Table 3.1 : Comparison of Australian Dam Owners

Dam Safety Activity	Goulburn Murray Water	Melbourne Water	Southern Rural Water	Wimmera Mallee Water	South Gippsland	Coliban Water	NSW State Water	Snowy Hydro	Sydney Water	Hunter Water	SA Water	Sun Water	SEQ Water	Hydro Tasmania	Water Corp
Number of Major Dams	*17*	*11*	*14*	*12*	*14*	*10* (50)	*18* (280)	*20*	*30*	*5*	*16*	*28*	*3*	*15* (54)	*17* (70)
Asset Value $ Mil	*1500*	*1000*	*300*	*250*	*150*	*200*	*2300*	*2500*	*2400*	*300*	*700*	*900*	*400*	*2000*	*1200*
Portfolio Risk Assessment	✓		✓		✓	✓	✓	✓			✓		✓	✓	✓
Engineering Consultant Panel	✓	✓	✓	✓	✓	**	**	**	*	**	✓	✓*	✓	*	✓*
Design Reviews	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓*	✓	✓	✓
Independent Expert Reviews	✓	✓	✓			✓	✓	✓			✓	✓	✓	✓	✓
Detailed Risk Assessments	✓	✓	✓	✓		✓	✓							✓	
Stakeholder Panel	✓		✓			✓	✓								
Strategic Plan	✓		✓			✓	✓	✓			✓	✓	✓	✓	✓
Monitoring, DSEP	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓
Remedial Works	✓	✓	✓	✓			✓		✓	✓	✓		✓	✓	✓
Annual Expenditure $ Mil	*10*	*2*	*3*	*1*	-	*7*	*20*	*10*	-	*1*	*5*	-	*5*	*2*	*10*

Notes: * Most work completed in-house
** Work tendered to invited consultants

3.2 OUR UNDERSTANDING OF THE WAROONA PROCESS

Waroona Dam was the first of the South West Dams operated by Harvey Water to be addressed in terms of dam safety. What process has Water Corporation followed in this case?

Since 1988, Water Corporation has upgraded 16 dams generally to achieve modern engineering design standards. A useful summary of the extensive remedial works program is provided by Wark, Vitharana and Somerford (2000)[24] This paper states that *"while risk assessment is currently used to prioritise projects, remedial works are still being designed to meet contemporary dam engineering standards albeit, in some cases through staged upgrading."*

Bob Wark reported to us:

> *"The deficiencies with many of these dams had been known for some time and a number of investigations had been undertaken to provide background data for the Safety Reviews. However, where more investigation was required, this was recommended as an outcome of the Safety Reviews. Typically at Harvey Weir, where the post tensioned remedial works had exceeded their design life, a condition assessment of the cables was undertaken.*
>
> *The Canning Dam Project was based on a risk assessment that identified flood, seismic and concrete deterioration as the main risks and developed an interim operating strategy to manage those risks to more acceptable levels until the remedial work could be undertaken. The dam had been well instrumented over the last 20 years or so and there was a wealth of operational data available. However, in addition the Canning work included significant new investigations of the condition of the concrete and foundation conditions. This work identified and resolved a problem with high pore pressures in the foundation.*

Remedial works for Canning Dam have now been completed, including 170 post tensioned anchors up to 140m long with 91 strand tendons and upgrade to the outlet works.

Water Corporation first conducted a portfolio risk assessment in 1997 to identify the dams which presented the highest dam safety risk and had the highest priority for design reviews. This exercise identified 17 dams out of the entire 55 dam portfolio across the State for design reviews. All six of the South West Dams were included in priority list.

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[24] Wark, R, N Vitharana, M Somerford (2000) "Dam Remedial Works in Western Australia" ANCOLD 2000 Conference on Dams, Cairns, October.

Geo-Eng, who are the dam engineering group privatised from the previous Western Australian Water Authority (WAWA) in 1996, were commissioned in 1997-1998 to carry out the urgent design reviews for all 17 priority dams. At that time, Water Corporation did not have an engineering consultant panel. At the same time, standards-based dam safety upgrade work was initiated at Canning Dam. The design reviews were comprehensive but relied principally on existing information and did not include any new investigations. Preliminary analytical studies were completed including embankment stability analyses, piping assessments, flood routing and dam break studies, structural stability calculations, among others. Previous WAWA work provided preliminary hydrologic inputs for each dam.

The design reviews included simplified failure modes and effects studies to identify critical dam safety issues and the preliminary design analyses identified a number of dam safety deficiencies. Preliminary risk assessment techniques were used to quantify the various risks and create societal risk f-N curves.[25] A single total risk F-N pair was computed to provide an overall risk profile for the 17 dams. From this risk profile, Waroona was selected as the first South West Dam for upgrade.

A concept design study and geotechnical investigation was commenced in 1999 for Waroona. Again Geo-Eng was commissioned to complete this work. At this stage Graeme Bell of SMEC, who was providing independent design review for Harvey Dam construction, was asked to provide independent review of the concept design activities. He also brought in Professor Robin Fell to assist with the piping and embankment stability issues. Bell and Fell in their review report raised a number of issues, but generally endorsed the concept design activities. Several comments provide important guidance to the design team:

> *The feeling of most who are involved is that seepage from an embankment or from a soil-type foundation must increase the chances of piping to develop. However, if seepage flows into a properly designed filter system and is taken to a discharge point by a drainage system with an adequate capacity, then the chances of piping are very low.*
>
> *Use of the method on other dams has shown that the UNSW method does not take full account of works which have been constructed to control the exit of seepage in the foundation. Thus, if a blanket filter / drain intercepts the seepage so that the fines are definitely not going to be moved by the exiting seepage and the seepage is directed away in a controlled manner, the UNSW method would still come up with a similar annual likelihood value to the pre-blanket layout. This result is contrary to good engineering design outcomes. There would be at least an order of magnitude reduction in the annual likelihood value.*

25 "*F-N curves are a graphical representation of the relationship between the annual probability of an event causing N or more fatalities, and the number of fatalities*" DEFRA (2002) *Reservoir Safety – Floods and Reservoir Safety Integration*, Main Report, August, p. 45

> *Before any decision on a downstream stabilising fill is made, it is necessary to keep in mind the concentrated leak through the dam problem. It is agreed that the sand chimney filter would stop soil fines being moved, but the chimney's drainage capacity may not be enough to stop local saturation of the downstream shoulder. At full height stabilising fill would resolve all concerns with that situation, but the question really is: "Are the chances of saturation of the downstream shoulder so low that the shoulder is acceptable as it is?" This aspect can be considered further when the additional analysis is completed. It should be noted that there seems to be no evidence of a concentrated leak ever having formed in the dam embankment. If so, then given that the dam's deformation behaviour is as expected and that the abutments are generally moderate in slope and fairly uniform, the chances of a concentrated leak ever developing through the dam wall in the future are very small indeed.*

The design team was then called upon to judge the importance of these potential mitigating factors on the piping risk, along with subsequent work completed in the workshop/design review phase to support the decision making process on the project.

Bell was again retained in 2000 and 2001 to review the final concept design and subsequent detailed design. At this stage his review focussed on optimising the effectiveness of the remedial works. Current best practice followed in the eastern states and in the USA, would have now utilised the results of the concept design studies in a detailed risk assessment to produce updated risk levels. This would have provided a sound and defensible basis for making a decision on the urgency in proceeding with the works and the opportunity for staging the works.

We understand that the preliminary risk assessment was never re-visited as the concept and detailed design studies were being undertaken, and the new information did not indicate any significant changes. The remedial works were designed to achieve standards-based criteria and were optimised to address as many deficiencies as possible in the single construction effort. This will be examined further in the next Chapter.

David Bowles was retained in 2001 to review the process followed by Water Corporation in its portfolio risk assessment and prioritisation process. He was not asked to address any of the inputs to the process as they were taken as given. Based on the given risk levels, he identified 30 risk reduction measures or Separable Construction Upgrade Packages (SCUPs) to be implemented in sequence to obtain the optimum risk reduction for each investment. He provided a graphical representation of the cumulative level of risk reduction for the optimum sequence of works in Figure 3.1. Although it was reported to us that actual implementation of risk reduction measures usually follows this prioritisation process in staging works, Waroona was a case where risk reduction works have been bundled together to achieve a standards-based fix. We understand that the prioritisation process is frequently reassessed as new data become available and projects are shifted based on their risk level. An example cited by Michael Somerford was Bottle Creek which was not in the original program but based on recent investigation has been elevated to the next priority.

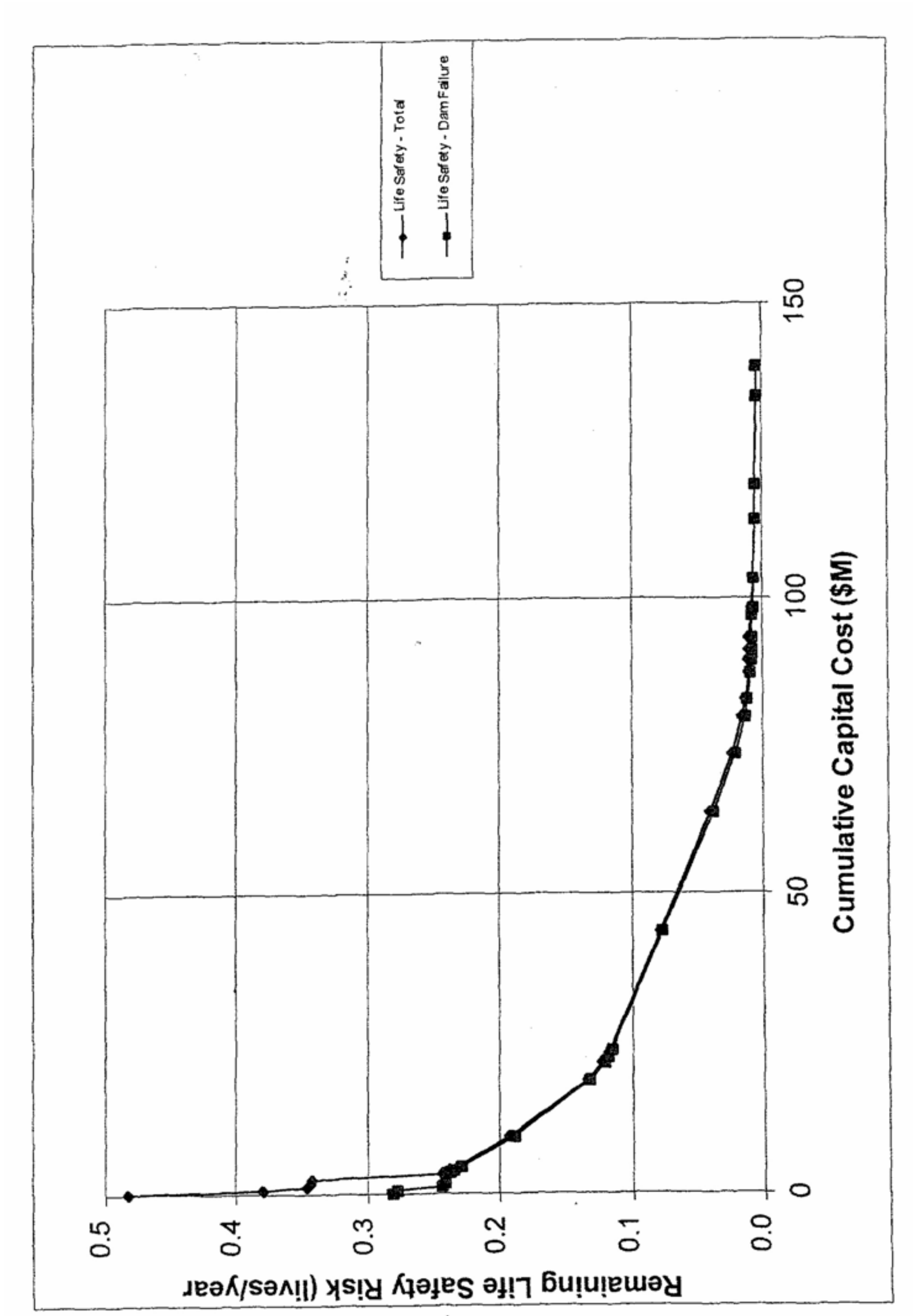


Figure 3.1 : Risk Reduction Profile for Prioritised Base Case from Bowles (2001)

Waroona actually had 3 risk reduction actions out of 30 in the Bowles (2001) PAR review ranging from increased monitoring (number 1) to two phases of works to upgrade the spillway (numbers 10 and 29), foundation drainage system and downstream embankment slope (Table 3.2).

Table 3.2 : Waroona Dam PAR Actions

Action	Capital Cost ($ M)	CPSLS ($ M)	Adjusted CPSLS ($ M)
1. Monitoring	0.6	0.5	0.4
10. Phase I Works	9.3	13.0	7.8
29. Phase II Works	15.0	1300	1300
Waroona Total	24.9		

CPSLS Cost per statistical life saved

Source : Bowles (2001)

One means to assess the effectiveness of the risk reduction works is the cost per statistical life saved (CPSLS), which divides the capital cost of the remedial works by the estimated number of lives lost in a dam failure. Although many organisations do not subscribe to this measure of cost effectiveness, it shows good value for increased monitoring, less value for the Phase I works and relatively ineffective investment for the Phase II works. High CPSLS actions are often implemented with some urgency if the societal risk levels are intolerable. However, if the risks fall below the tolerability threshold, then they are subject to the ALARP principle and CPSLS is scrutinised more closely. Other owners require benefit cost ratio calculations or development of a business case to justify that specific works are required to reduce risk as low as reasonably practicable. We concur with Water Corporation that the use of CPSLS should be strictly limited to prioritisation of similar dam safety projects, not in making a decision on whether a project should proceed.

At Waroona, based on the preliminary risk assessment, risks from piping, embankment and foundation stability and flood are all intolerable which has driven the urgency of the works. We have provided an independent assessment of those risk levels in the next Chapter.

We understand that the decision in 2002 to proceed with the Waroona upgrade project was based on a detailed business case and included considerable community consultation. Unfortunately, Harvey Water was not a part of this process and as a key stakeholder did not have any review role until this current stage. Stakeholder involvement is a relatively new element to the dam safety management process, but would have been a very useful means of communication and feedback

4 ENGINEERING INPUTS

The purpose of this chapter is to review each of the major engineering inputs into the risk assessments undertaken for Waroona and, where relevant, the other five dams. The inputs reviewed are:

- assessment of hydrological risk;
- piping assessments;
- stability;
- outlet assessments; and
- consequential assessments.

4.1 ASSESSMENT OF HYDROLOGICAL RISK

4.1.1 GENERAL

The likelihood that a dam is overtopped by floods is determined by a hydrological analysis of extreme rainfalls and floods. There are two basic components to estimating overtopping probabilities:

- firstly it is necessary to estimate flood magnitudes ranging from around the largest on record up to the largest that could be reasonably expected, and
- secondly the capacity of the spillway to handle floods over the range of possible magnitudes and durations needs to be assessed.

In Australia the guidelines covering the hydrological methods that can be used to estimate extreme floods is published by the Institution of Engineers, Australia (Nathan and Weinmann, 1999 – Book VI of Australian Rainfall and Runoff or ARR99). Typically it is required to estimate floods with an annual exceedance probability[26] (AEP) of between 1 in 50 and 1 in 10 million. The Australian National Committee on Large Dams (ANCOLD, 2000b) provide recommendations related to the second component, that is on most aspects of spillway capacity and safety levels for all water retaining structures.

This review has concentrated on the series of hydrology reports prepared over the past ten years by (for the most part) the Surface Water Hydrology Section of the Water and Rivers Commission. In general two reports are available for each dam: the first, more detailed reports were prepared in the early 1990s, and the second revised reports were subsequently undertaken over the period 2000 to 2001. The revised reports are generally available only in summary form, and thus for most details it was necessary to refer to the earlier reports. This causes some difficulties as the later series of reports introduce some important changes (most notably relevant to the consideration of shorter duration

[26] Annual exceedance probability (AEP) is the term given to the chance that a flood of a given (or a larger) size occurs in *any one year*. Thus, a “1 in 100 AEP” flood represents a flood that has a one-in-one hundred chance of being exceeded in any year.

rainfall events and the treatment of baseflow), the precise details of which are not well documented. Overall, the level of documentation available is adequate for the purposes of reviewing the *procedures* adopted, though the defensibility of the *specific* flood estimates is made difficult by the brief nature of the later reports.

The following section summarises the main conclusions from the hydrological review, and the technical discussion on which these comments are based appears in Appendix A. In order to assess the likely impact of the identified issues on the estimation of overtopping risks some investigative – and at times only exploratory – analyses have been undertaken. These analyses have been undertaken merely to illustrate the likely benefits and implications of adopting different approaches; they do not represent alternative design estimates. The nature of the investigations undertaken are also presented in Appendix A.

4.1.2 SALIENT COMMENTS

The procedures used to characterise hydrologic risk in the South West Dams are broadly consistent with the ARR99 guidelines. However, there are a number of areas in which the adopted procedures differ from design practice used commonly in other parts of Australia. The main areas of departure from common design practice are related to the:

- seasonal variation in the salient flood producing mechanisms;
- manner in which rainfall losses are estimated; and,
- estimation of baseflows associated with extreme events.

There are sound theoretical reasons for tailoring the flood estimation approaches to the unique characteristics found in this region, and it is clear that the practitioners involved in estimating the floods for these dams have given the relevant issues careful thought.

Overall, it is considered that the general approaches and procedures used in the studies are appropriate, and that the main points of departure from established practice are conceptually desirable. However, there are a number of areas in which it is considered that the accuracy and defensibility of the estimates could be improved, and these are discussed below.

4.1.3 DESIGN RAINFALLS

The design rainfall information used to date is appropriate for the required purpose. It is noted that recently the Bureau of Meteorology have updated its (seasonal and annual) estimates of Probable Maximum Precipitation (PMP), and this new information should provide an increased level of confidence in the results. The stated intention by Water Corporation hydrologists to use a sample of temporal patterns in lieu of a single fixed temporal pattern is endorsed.

It is recommended that some regional analysis be undertaken to derive design information on “pre-burst” rainfalls (that is on the depth of rainfall that is likely to occur immediately prior to the intense design bursts provided by the Bureau of Meteorology). This would assist the validation of the loss models (when used in conjunction with independent estimates of design floods) and would aid extrapolation of the results to extreme events.

It is also recommended that some regional analysis be undertaken to identify the seasonality of 1 in 100 AEP short duration rainfalls (six hours and less) as at present it is not clear on what basis these have been derived.

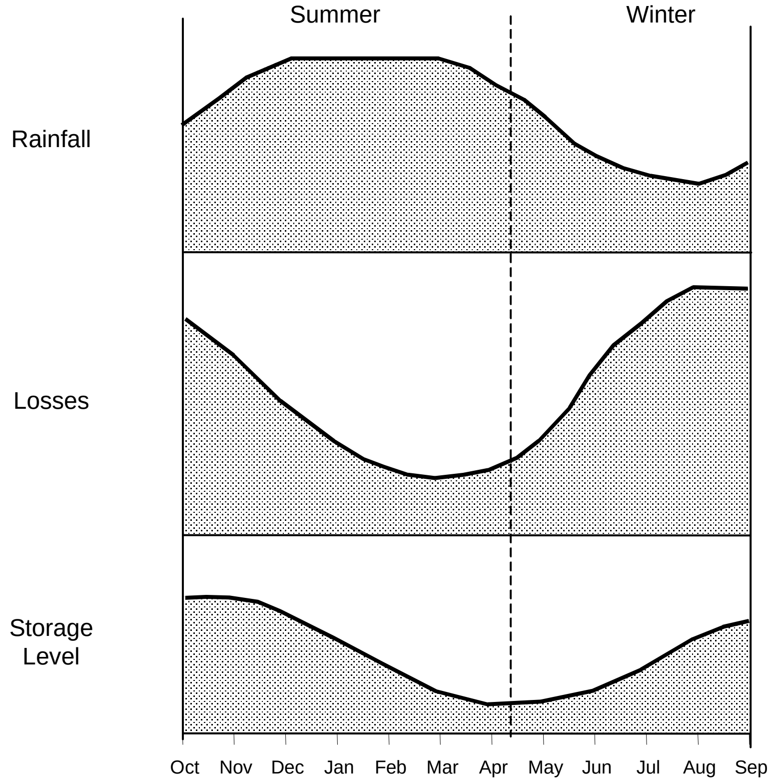
Water Corporation's scheduled work program for derivation of intermediate rainfalls (using the CRC-FORGE approach) will have most relevance to catchments where longer duration rainfalls are relevant. These include Wellington Dam, and those dams for which initial drawdown has an appreciable influence on the outflow flood. For other dams, research could be undertaken to examine the likely relationship between short-duration thunderstorm events and longer duration events, and it may be feasible to use such information to extrapolate CRCC-FORGE results to shorter durations.

4.1.4 SEASONALITY

At present the analyses are based on dividing the year into two seasons (Oct-Apr, May-Sep). However, as illustrated in Figure 4.1, it appears reasonably possible that if only two seasons are selected then unlikely combinations of factors may result. For example, with the specified seasonality, high rainfalls could occur with either high or low losses, and in terms of outflows, these may coincide with either low or high initial reservoir conditions.

Preliminary analyses indicate that consideration of four seasons rather than two may be more appropriate (the occurrence of rainfall maxima is divided into summer and winter, and other inputs are divided into four seasons, namely Oct-Dec, Jan-Apr, May-Jun, Jul-Sep). Exploratory investigation indicates that (if the model is adequately calibrated) there will perhaps be little difference in the magnitude of the inflow flood, but there may be an increase in the likelihood of overtopping due to the seasonal distribution of storage level.

Figure 4.1 : Schematic illustration of the seasonality of some flood modifying factors



4.1.5 LOSSES

Losses associated with extreme rainfall events are generally assumed to be low or zero in many parts of Australia. In addition, it is common to assume that loss rates are constant throughout the duration of the rainfall event.

By contrast, the loss values assumed for the South West catchments are far higher than used elsewhere in Australia, and they are allowed to vary over the duration of the event. The losses are estimated using a conceptual model developed by Stokes (1989), the details of which are described in an unpublished report (by the Water Authority of Western Australia). Although the conceptual basis of the loss modelling used is appreciably different to that used elsewhere in Australia, it appears to be well founded on empirical evidence and appropriate to the unique characteristics of the region. The use of field data to derive the soil water storage characteristics and their spatial variation for different landform classes, also seems to be a strength of the adopted approach.

However, while the conceptual basis of the method is defensible, it is considered that the manner in which it is applied in practice could be improved upon. There are several aspects to this, and these can be summarised as follows:

- there are some conceptual difficulties with the manner in which the model is calibrated and then used to estimate design floods; and

- the model at present is based on the use of fixed seasonal initial moisture conditions, and preliminary analyses indicate that different (possibly lower) design flood estimates might be obtained when used with a distribution of values.

There are ways in which the available information could be better incorporated to minimise the difficulties associated with the loss modelling, and these are discussed in Appendix A.

4.1.6 BASEFLOW

For most of Australia baseflow[27] incorporated into the results is small compared with direct runoff, especially for extreme floods, and in some regions it may be neglected. In the south west of Western Australia baseflow is an appreciable proportion of observed floods and thus it is appropriate to adopt higher values than generally used elsewhere. However, the justification used to estimate baseflow for extreme events in the south-west catchments is not clear (in terms of magnitude and timing), and some evidence needs to be provided to assess the appropriateness of the adopted values.

4.1.7 PARAMETER IDENTIFICATION

At present the studies have relied solely on the ability of the model to reproduce historic flood events that are around 1/10 to 1/80 the magnitude of the final PMP Design Floods. It is considered that better use could be made of regional information, particularly with respect to comparing the results obtained using independent methods (such as those based on at-site/regional flood frequency analyses). More use could be made of the existing information of the seasonal variation of rainfall events

4.1.8 INITIAL STORAGE ASSUMPTIONS

At present, all studies have assumed that the initial water level in the reservoir will be at full supply level. This assumption may be unnecessarily conservative, and it is possible for some of the storages that the consideration of initial drawdown will reduce the estimated likelihood of overtopping failure. It is understood that drawdown was considered in the original studies and judged to be of little significance, however no documentation on this has been provided.

4.1.9 SENSITIVITY & UNCERTAINTY ANALYSES

The studies include a sensitivity analysis that is aimed at reflecting the uncertainty in the parameter estimates and likely increases due to land-use (bauxite mining) and climate change. The sensitivity analysis of parameter uncertainty used in the earlier reports is misleading (and is omitted in the later reports), and the analysis of climate change is not supported. The estimates of likely flood increases due to bauxite mining are based on a reasonably premise and should be retained.

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[27] Baseflow is the component of the flood hydrograph that results from lateral subsurface or groundwater inflows – this is discussed in more detail in Section A5.

4.1.10 SUMMARY

The methods used to estimate extreme floods in this region depart in some significant respects from established practice used elsewhere in Australia. Overall, it is considered that there is strong theoretical justification for incorporating seasonality and the adopted loss model, however the manner these considerations are dealt with in practice could be improved upon.

It is difficult to predict what the overall impact on the estimated likelihood of overtopping failure would be if the salient issues were addressed. It is possible that resolution of the most important issues will result in lower estimates of overtopping failure, though the main uncertainty here is the impact arising from review of the parameter values using independent estimates of (more frequent) design floods.

While some of the additional investigations discussed in this review may be considered onerous to undertake for a single dam, the benefits can be attributed to the whole portfolio of south-west dams and thus they are easily justified.

A summary of the nature and assessed degree of importance of the hydrological issues raised is presented in Table 4.1.

Table 4.1 : Summary of nature and degree of importance of hydrological issues raised

Issue raised	*Likely impact on results if issue addressed*	*Degree of Importance to defensibility of results*
Reconciliation of seasonal rainfall-based flood estimates with at-site /regional flood quartiles	Unknown impact on flood magnitude, but greater confidence in results and increased defensibility.	High to Very High
Initial reservoir level	Estimated likelihood of overtopping will either remain unchanged or will reduce (particularly Logue Brook, and any other dam that is likely to be drawn down below full supply level).	High to Very High
Manner in which baseflow incorporated	Flood peaks and estimated likelihood of overtopping may reduce.	High
Initial soil moisture conditions treated as a variable rather than as a fixed value	Flood peaks and estimated likelihood of overtopping may reduce.	High
Analysis based on four rather than two seasons	Unclear, though possibly a net decrease in estimated likelihood of overtopping due to seasonal interaction with initial storage level	Medium to High
Incorporation of additional information on seasonality of short-duration rainfalls	Unknown impact on flood magnitude, but greater confidence in results and increased defensibility.	Medium
Incorporation of pre-burst rainfall proportions for all durations	If model adequately calibrated then this may have little impact on results, but will provide greater defensibility of results in cases where calibration data are limited.	Medium
Use of sample of temporal patterns rather than single fixed pattern	Uncertain impact on flood magnitude, though of high importance in estimating the Probable Maximum Flood (as distinct from the PMP Design Flood).	Medium (for probabilistic floods) High (for PMF)
Incorporation of long duration CRC-FORGE rainfalls	Experience elsewhere indicates that estimates of overtopping likelihood generally reduce (though not always the case), though will provide greater defensibility of results for dams where longer durations are relevant.	Low (for most storages) High (certainly for Wellington Dam, and others where initial drawdown is important)
Treatment of sensitivity analyses	At present results for climate change and parameter uncertainty are misleading.	Low

4.2 PIPING ASSESSMENTS

4.2.1 STANDARDS CRITERIA

The main design principle for a standards-based assessment of piping in embankment dams is the provision of multiple lines of defence. The most important of these is the provision of properly designed and constructed filter and drainage elements, which prevent the internal erosion of embankment and foundation materials by seepage. Other piping control measures include provision of a low permeability core, good compaction of embankment materials, foundation treatment including abutment shaping to prevent cracking of the core, and provision of a fully penetrating cut-off in the foundation.

The importance of filters to control erosion was not widely recognised until the 1960s and 1970s, and filter design criteria used today were developed in the 1980s. Many embankment dams were constructed prior to this period and hence they do not have embankment filters or have filters that do not meet modern design criteria. Despite this, many of these embankment dams have performed well owing to the good performance of the core or good erosion resistance of the embankment and foundation materials.

4.2.2 RISK FRAMEWORK

In a risk framework, piping potential is considered in terms of the probability of piping failure. There are two methods for estimating the probability of piping failure; the historic performance methods and event tree methods. The historic performance method is based on the historic frequencies of failure of embankment dams and is only applicable to preliminary or portfolio risk assessments. The draft ANCOLD (2001) risk guidelines recommend event tree methods be used for detailed risk assessments. This method considers the sequence of events that are required for failure to occur.

The risk assessments carried out by Geo-Eng have used the historic performance method, and while appropriate for the portfolio risk study, they are not appropriate for detailed assessments required for decision making or selection of preferred remediation options.

For future Safety Review and Remedial Design studies, Water Corporation should perform detailed assessment of piping potential similar to those described in Foster & Fell (2000) and Foster *et al* (2001). The studies should also incorporate an assessment of the filter compatibility between adjacent zones within the dam and foundation and this should include sampling of filters to confirm as built gradings. Experience from recent studies of other dams in Australia of similar age to the SW Irrigation dams is that the filter materials are often of poor quality and do not meet current design criteria. Fortunately, we understand that where present, the filter sands used in the Harvey Water dams may be compatible with the foundation and embankment soils.

We understand that Water Corporation has reservations about the use of quantitative risk assessment (QRA) and have highlighted the negative comments from one peer reviewer, Dr Des Hartford of BC Hydro on the draft ANCOLD risk guidelines. However, we understand that the essence of Hartford's concerns relate to its use to justify a risk-based upgrade in lieu of satisfying modern engineering design standards. We concur and do not support this use of risk assessment. The target for any dam safety upgrade must always be to eventually meet modern engineering standards. John Smart of the Bureau of Reclamation in his comments on the draft guideline challenges ANCOLD to come up with any better means of establishing priorities for dam safety upgrades with the limited funding available to most dam owners. His sentiments are echoed by Ray Stewart of BC Hydro recently that the risk-based approach achieves extremely valuable outcomes in prioritising dam safety works. With useful overseas precedent and over five years of successful implementation in Australia, most Australian dam owners are actively using quantitative risk assessment as demonstrated in Table 3.1.

4.2.3 WAROONA DAM

The 1999 Safety Review and 2000 Definition Reports by Geo-Eng concluded Waroona Dam (Plate 4.1) has an unacceptable potential for piping failure through the foundation. Their assessment was based on the observed excessive seepage through the foundation and high pore pressures that are present in the abutment foundations (Figure 4.2). Investigations indicate the seepage is primarily occurring through permeable residual materials in the abutment foundations (Figure 4.2), which are not intercepted by the foundation cut-off trench. The high pore pressures are the result of lower permeability materials overlying the more permeable zones, which causes a confining effect on the seepage flow path.

While the seepage is relatively high for a structure of this type and height, the majority of foundation seepage at Waroona Dam is intercepted by a drainage system. The Review Panel's Report (October 1999) estimated that 75 to 80 % of the seepage is collected and led away by the existing drainage system. This is comprised of a weighted drainage blanket and relief wells (Figure 4.3) that was installed along the downstream toe of the dam soon after construction in response to a seepage incident once the reservoir was filled.

The drainage system is deficient in that the gravel backfill in the relief wells probably does not meet filter criteria. Despite this deficiency, the drainage system appears to have performed its function adequately for the past 35 years, albeit requiring ongoing maintenance. Seepage does emerge downstream of the drainage system, however it appears to be wide spread and such seepage patterns are much less conducive to piping than concentrated seepage paths.

Figure 4.2 : Waroona Dam – High Pore Pressures in Left Abutment

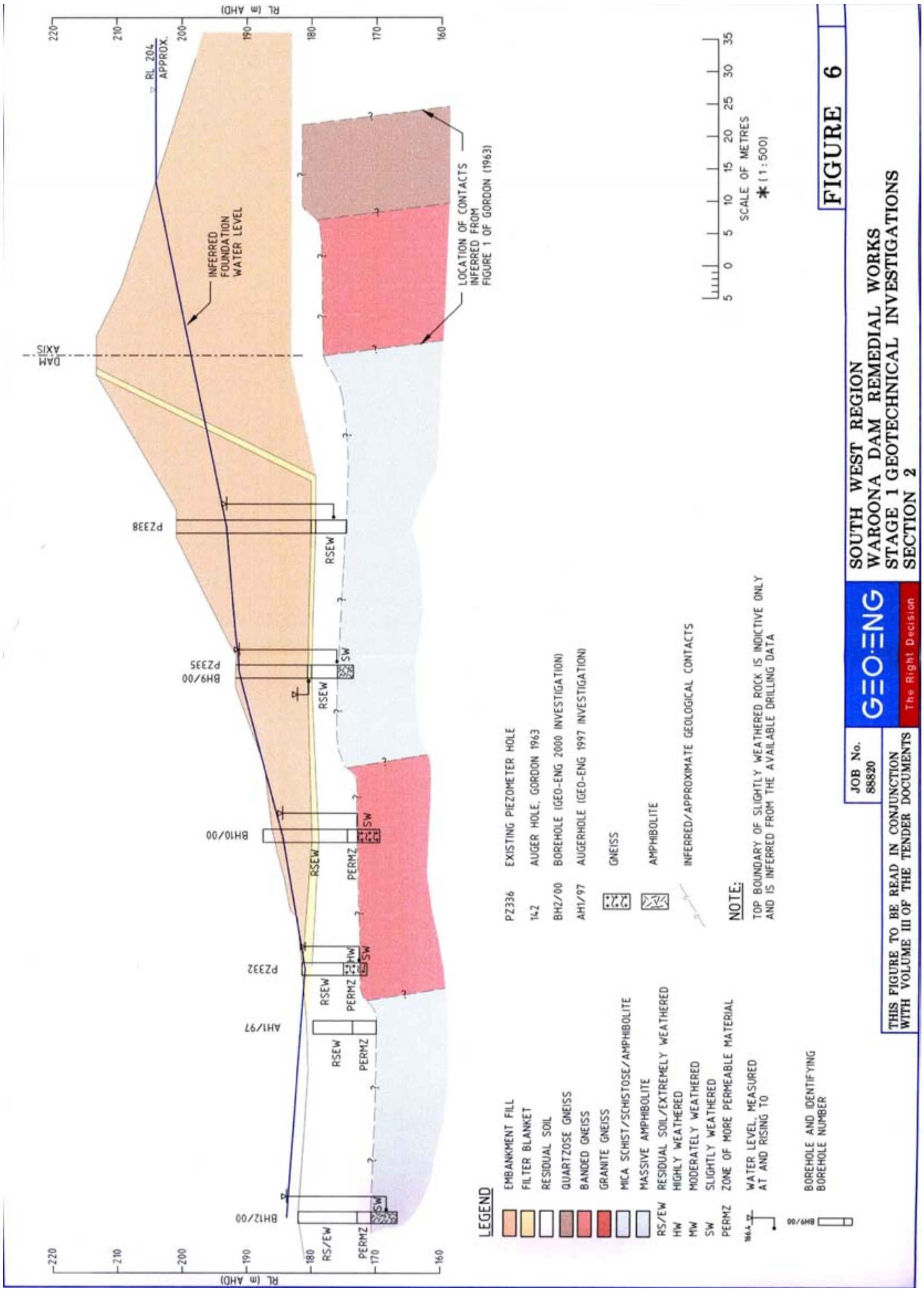

Figure 4.3 : Waroona Dam Toe Drain

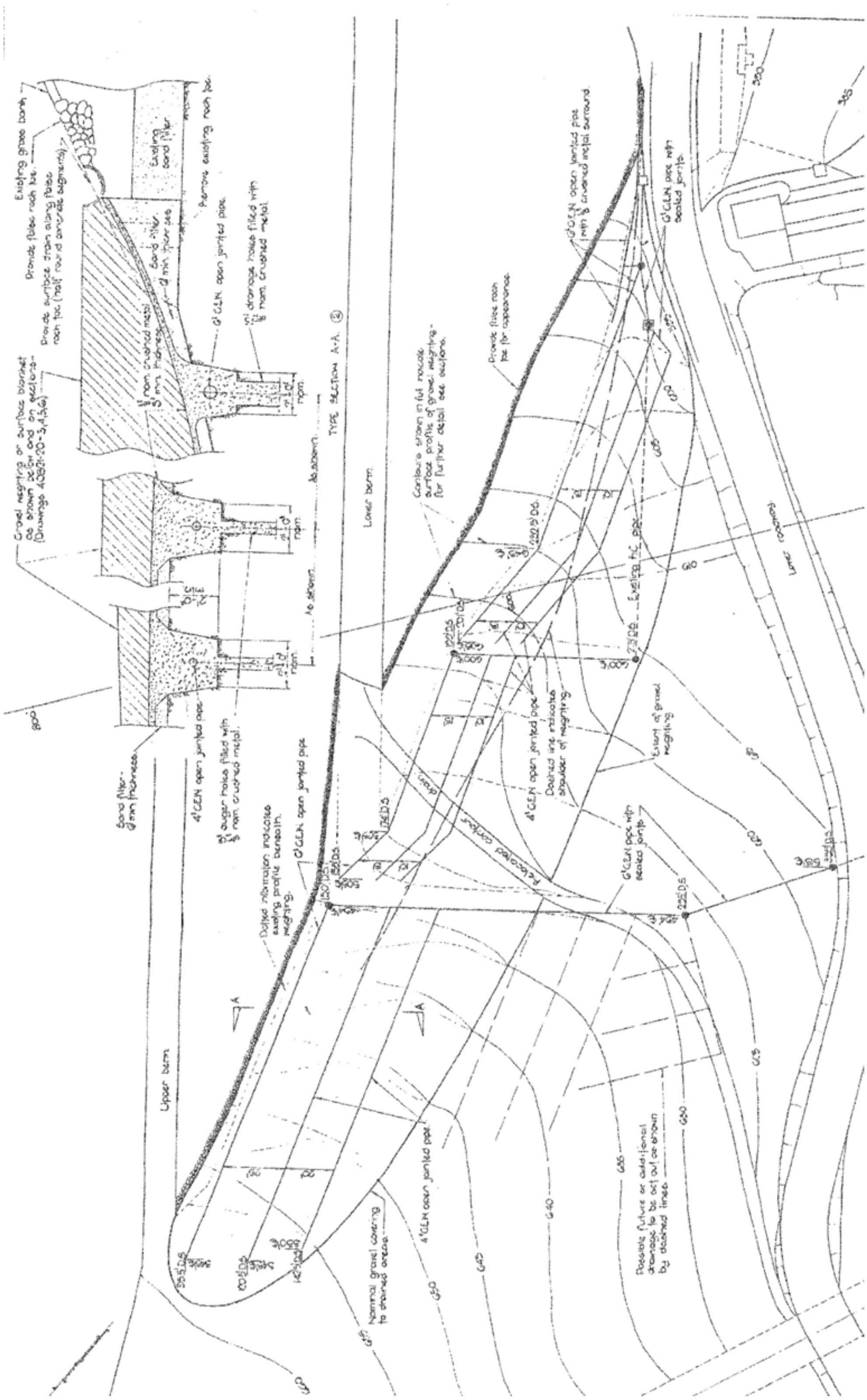

Plate 4.1 : Waroona Dam

Plate 4.2: Seepage holes within the right abutment downstream of the embankment

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The observed performance and monitoring data suggests piping has not occurred in the dam or foundation to date. There is no reported evidence of erosion of materials from the foundation or embankment, and the measured seepage flows and pore pressures have not shown any long-term increasing trends, which would be expected if piping was occurring. However, the postulated deficiencies in the design of the drainage system raises concern over its potential for deterioration and plugging in the long term. If this were to eventuate, then there would be an increased risk of embankment failure due to rising foundation pore pressures leading to embankment instability or foundation blow out.

The Geo-Eng studies also concluded an unacceptable potential for a ‘blow out’ condition developing at some locations owing to the high pore pressures in the abutment foundations. However, they have adopted a conservative approach for calculating the factor of safety against blow out failure by extrapolating the piezometer readings, which measure the pore pressure at depth, to the surface. The pore pressures, and hence factor of safety against blow out, would tend to decrease at shallower depths. Table 4.2 shows the calculated factors of safety for blow out when calculated at the actual depth of pore pressure measurement. The results indicate acceptable values (i.e., $FS \geq 1.5$) except at one location, BH13, which is located some 50m downstream of the toe on the left abutment and at this distance unlikely to be detrimental to the safety of the dam. The low potential for a blow-out condition is supported by the dam behaviour, with no reported evidence of sand boils, sinkholes, cracking or ground heaving that are usually associated with marginal blow-out conditions.

We concur with Geo-Eng’s assessment of the low potential for piping through the dam, despite the less than desirable width and drainage capacity of the chimney filter. The monitoring data indicate that the core is performing well and the absence of pore pressures measured within the downstream shoulder indicates the chimney filter has adequate drainage capacity for the current operating conditions. The chimney filter does not extend to Full Supply Level and this increases the potential for piping under earthquake and flood loading conditions if concentrated leaks were to develop above the top of the filter. This is a deficiency in terms of standards based design principles, however in a risk framework the potential for piping to develop above the filter is low due to the relatively high erosion resistance of the core materials.

Table 4.2 : Waroona Dam – Factor of Safety Against Blow Out Condition

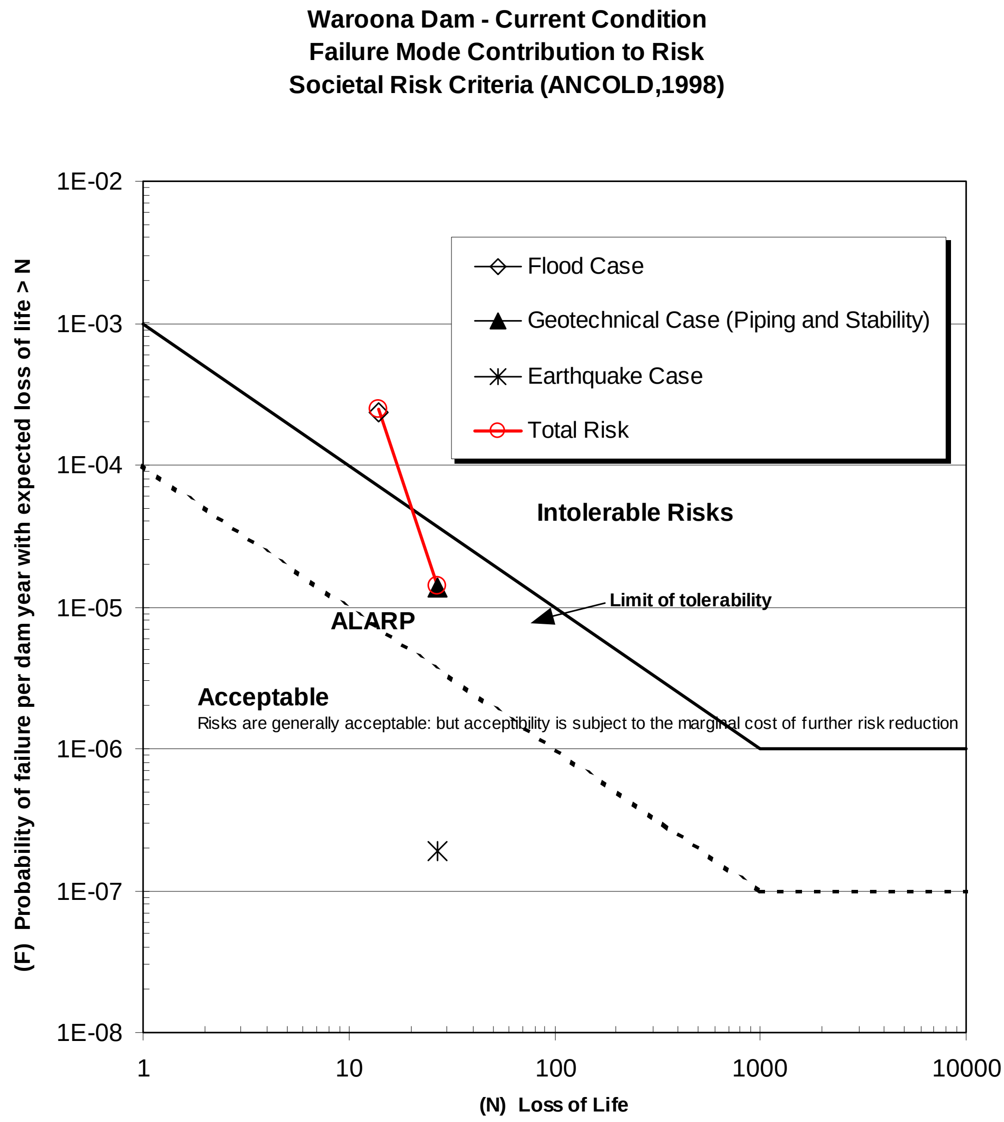
Piezometer No.	Surface Elevation (RL m)	Depth to Top of Screen	Max.Measured Water Head (RL Elevation)	Hp	Factor of Safety Blow Up
PZ329	201.2	11.7	195.8	6.3	3.51
PZ330	192	12.5	189	9.5	2.49
PZ331	191.6	11.3	188	7.7	2.77
PZ332	181	7.5	181	7.5	1.89
PZ333	200.6	13.9	190.3	3.6	7.30
PZ334	191.6	10.4	190.7	9.5	2.07
PZ335	192	14	191.5	13.5	1.96
PZ336	191.7	15.4	186.3	10	2.91
PZ338	200.7	20.4	193.3	13	2.97
PZ339	192.1	13.9	188.6	10.4	2.53
PZ340	200.7	8.5	196.6	4.4	3.65
PZ341	184.9	3.7	182	0.8	8.74
BH1	200.19	18.5	196.1	14.44	2.42
BH2	195.01	8.3	193.7	7.01	2.24
BH3	185.95	12	184.9	10.92	2.08
BH4	185.83	7.2	185.9	7.23	1.88
BH5	182.44	5.4	183.1	6.028	1.69
BH6	179.23	10.3	179.7	10.77	1.81
BH7	191.42	9.4	189.4	7.34	2.42
BH8	191.72	13.2	182.9	4.4	5.67
BH9	191.63	12.5	182.2	3.06	7.72
BH10	187.29	13.6	184.6	10.95	2.35
BH11	190.77	11.1	188.2	8.54	2.46
BH12	182.1	11.2	184.6	13.74	1.54
BH13	186.03	9.4	190.8	14.12	1.26
BH14	181.05	6	181.8	6.75	1.68
BH15	180.99	8.1	182.4	9.55	1.60
BH16	181.78	14.2	180.2	12.66	2.12
BH17	176.85	-	176.2	-	-
BH18	190.31	11.1	186.6	7.39	2.84
BH19	195.02	27.6	190.2	22.74	2.29
BH20	190.36	20.1	187.5	17.22	2.21
BH21	180.46	16.7	181.1	17.374	1.82
BH22	187.66	11.3	188.1	11.785	1.81

Preliminary event trees have been developed as part of this independent review to assess the current risk of piping failure of Waroona Dam and to demonstrate the methodology. The assessment is based on the methods described in Foster and Fell (2000), and Foster, Fell, Davidson and Wan (2001). Event trees were developed for various flood and earthquake loading conditions as well as for normal operating conditions.

Normally, event trees would be developed in an expert panel workshop with the participation of the owner, designer, technical experts and operations staff. This broadly based participation usually brings out very useful historical performance information and provides a crucial sanity check by those most familiar with the dam. The process of developing the failure pathways in the event trees is generally the most useful element of the workshop as it forces the team to assess logically how each initiating event would have to develop and how various defensive design feature would affect the developing failure scenario. This often focuses the team on critical uncertainties that can then be investigated and quantified to define more reliably the actual risk. Here the ongoing safety review activities and design analyses provide crucial information in judging probabilities. The effectiveness of both structural and non-structural risk reduction measures can be debated, often leading to meaningful risk reduction just by changing certain monitoring or emergency protocols. Our experience is that the shared understanding of the behaviour of the dam that comes out of an expert panel workshop is generally more useful then any computed risk number. Unfortunately, a full blown expert panel workshop was not possible within the current review project, so the process was carried out by a limited URS team of Mark Foster and Dr Dick Davidson, relying only on our review of the information provided by Water Corporation and perceptions from the site visit.

Figure 4.4 shows the component f-N and total F-N curves plotted against the ANCOLD societal risk criteria. The event trees are provided in Appendix A. The annual probability of piping failure under normal operating conditions estimated using the event tree method is approximately an order of magnitude lower (1.2×10^{-5} per annum) than estimated by Geo-Eng using the historic performance statistics (1×10^{-4} per annum). The portion of the F-N curve contributed from foundation piping falls within the ALARP region.

Figure 4.4 : Waroona Dam Comparison of F-N Curve to ANCOLD Societal Risk Criteria



The main factors contributing to the lower probability of foundation piping are:

- while a seepage path already exists through the foundation, the majority of seepage is intercepted by a drainage system which is likely to prevent continuing erosion of the foundation materials;
- the seepage that is not intercepted by the drainage system is wide spread and has not shown signs of piping in over 35 years of performance; and
- even if piping were to initiate in the foundation, then there is a low chance of it progressing and leading to breach due to the long seepage path, likely good erosion resistance of the foundation soils, and the ability to detect and intervene. The extensive monitoring program would provide early warning of a developing situation.

According to ANCOLD guidelines, the measures to reduce risk levels should be subjected to the ALARP test, which considers the cost effectiveness, available funding and urgency of the works. A multiple line of defence solution has been developed which intercepts foundation seepage using the original drains but with a filter compatible blanket, increases drainage capacity of the chimney drain within a new downstream berm, and reduces seepage flows with an upstream clay blanket. In essence the proposed remedial works for Waroona Dam shown in Figure 4.5 will replace the current drainage system with a more effective and reliable system that prudently satisfies modern dam design standards.

However, with the lower computed piping risk falling below the intolerable limit, do the proposed piping upgrade works still have the same urgency compared with other issues across the Water Corporation portfolio?

We acknowledge that Water Corporation and its consultants strongly believed that the geotechnical risks at Waroona are intolerable and required urgent works to reduce this risk. However, careful review of the documentation provided to us and independent checks of key issues have not provided a compelling case for the urgency of the works, especially considering the required water losses during the current drought. We do not question the need for the works or their effectiveness in bringing the dam to a modern engineering standard. Although the case for staging the works has been addressed and dismissed as inefficient, we were not convinced.

4.2.4 Additional Information on Waroona Provided Since Issuing Draft Report

Since the issue of the draft report in December, both Water Corporation and GHD have provided very useful and relevant information for our consideration in finalising our report. Some of this information was not available in the reports provided for our review, some was for clarification, and some very important information was provided from site inspections during the current remedial works.

Key excerpts from the additional information provided by GHD and Water Corporation include:

> *The initiating event for the original remedial works was in fact a concentrated leak that occurred as the construction people were tidying up the rock toe some 18 months after construction was completed and the dam had filled. Several similar incidents have occurred since then, including sand boils and washing of sand into filter drainage systems. Concern with the adequacy of the system was one of the issues that led to the remedial works, particularly the design of systems that could be readily maintained. More recent observation during construction have identified blockage of the drainage pipes and filters as having occurred fairly extensively in the vertical drains, pipes and filter beds of the remedial works systems.*
>
> *During construction of the remedial works, observations of significant seepage into the downstream cutoff trenches and a trench excavated adjacent to the intake tower have confirmed my concern that concentrated*

> *leaks can develop in the foundations. Excavation of an investigation trench on the right abutment has heightened my concern about the potential for piping through the foundation. A sub horizontal zone at least 3 metres thick of very permeable (almost honeycombed) material was uncovered. Vertical sand filled old root canals ran from the surface into this zone. The current thinking of GHD, Graeme Bell and myself is that we underestimated the likelihood of piping through the foundations. We are all very pleased that we have proceeded with all of the remedial works.*

Much of this information supports the feeling of Water Corporation and its consultant team that the geotechnical risk is intolerable. We believe that an expert panel workshop would have brought out the reasons and basis for this sense of unacceptable risk that was not compellingly obvious to us in the supporting documentation. This would occur by asking probing questions like:

- *Have concentrated leaks ever been observed before? What about sand boils or other evidence of excessive uplift pressure?*
- *What is the honeycomb feature observed upstream in Plate 4.3? Does this extend downstream?*
- *What was the nature of the concentrated leak that led to the original remedial works?*
- *Has there been any evidence that the situation has deteriorated over the years?*
- *Could the drainage measures become fully plugged and inoperable? How quickly would this situation develop and what would be the response of the pore pressures within the foundation and embankment?*
- *How would Water Corporation operational staff respond to a developing incident?*

We have revisited our event trees provided in Appendix A in light of the new information and confirm that there is justification to increase the piping risk levels overall by about half an order of magnitude reflecting the increased likelihood of continuing erosion with the observed deterioration of the drainage system. This would push the overall risk into the “Unacceptable” region on the ANCOLD (1998) societal risk plot.

Through challenge and healthy debate, the expert panel workshop would work through these issues until full consensus was reached by all parties. Participation by Harvey Water would have been useful, because this would provide them with a clear understanding of the problem and an opportunity to contribute to developing an acceptable risk reduction strategy. Issues of drought management, transfer of water, funding and other matters would be fully considered in the final adopted strategy.

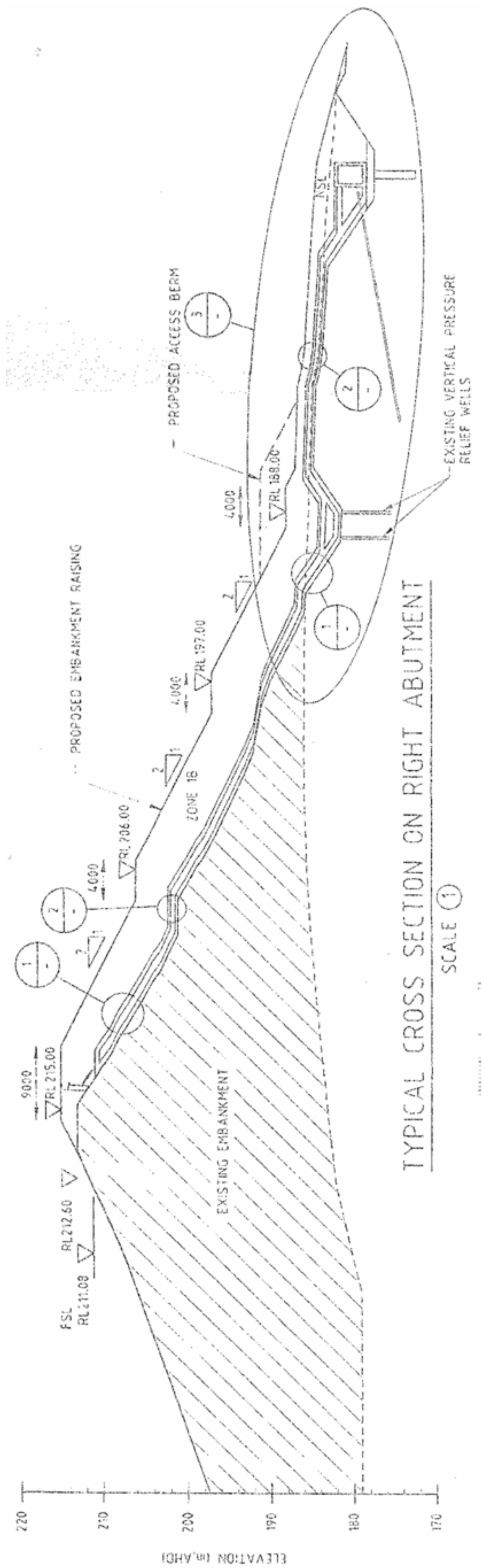
Plate 4.3 : Honeycomb feature below FSL along the upstream reservoir rim on the right abutment

4.2.5 STIRLING, LOGUE BROOK, SAMSON BROOK & DRAKESBROOK DAMS

Stirling, Logue Brook, Samson Brook and Drakesbrook Dams are all deficient in terms of standards based criteria. These dams either have no fully intercepting embankment filter (Samson Brook and Drakesbrook Dams) or do have a filter but which is deficient (Stirling and Logue Brook Dams).

Samson Brook Dam shown in Plate 4.4 and Figure 4.6 and Drakesbrook Dam shown in Plate 4.5 and Figure 4.7 are puddle clay earthfill dams and these typically do not have filters. Our experience with puddle clay earthfill dams is that they have performed well and do not show signs of piping unless there is a defect through the puddle core. Typically the piping potential of such dams with a good puddle core is assessed to be low, and relatively low probabilities of piping failure are estimated by event tree methods. Samson Brook Dam was assessed by Geo-Eng as having an unacceptable high piping risk compared with the ANCOLD societal risk guidelines. The historic performance method was used for estimating the probability of failure and our experience with this method is that it over estimates the failure probability in these cases. The monitoring data and observed performance indicate the puddle core is performing well at Samson Brook dam.

Figure 4.5 : Waroona Dam Proposed Remedial Works



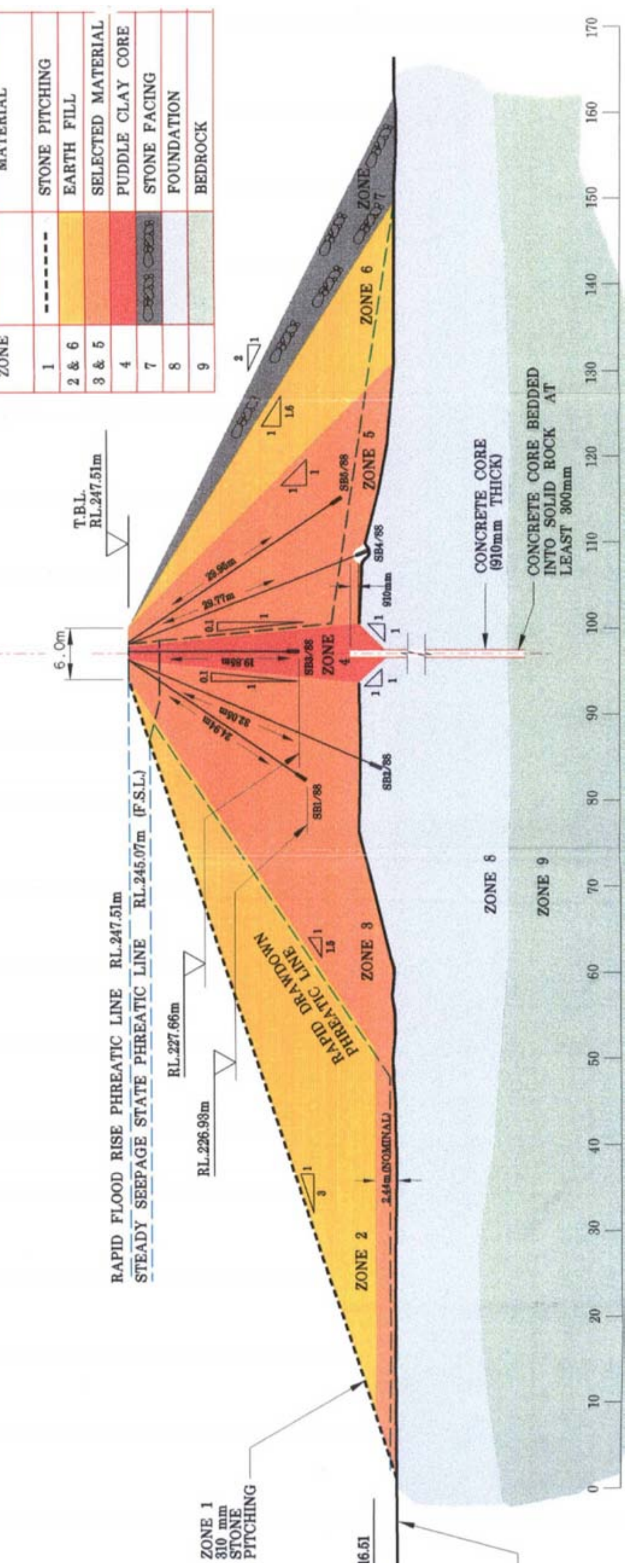


Figure 4.6 : Samson Brook Dam Section

Figure 4.7 : Drakesbrook Dam Section

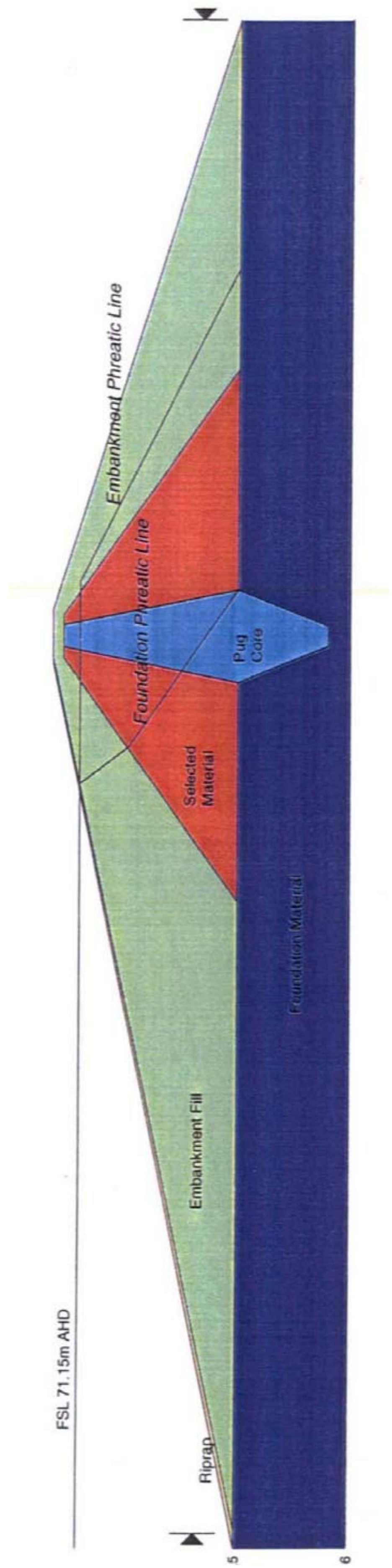


Plate 4.4 : Samson Brook Dam

Plate 4.5 Drakesbrook Dam

For Drakesbrook Dam, monitoring data indicate the existence of high pore pressures in the downstream shoulder and we concur with Geo-Eng's assessment that this is most likely due to seepage over the top of the puddle core. The piping risk has been assessed to be unacceptable by Geo-Eng based on the historic performance method. In this case, a more detailed piping assessment using event tree methods is likely to support this conclusion because of the increased risk associated with piping above the top of the puddle core under normal, flood and earthquake loading conditions.

Stirling Dam, shown in Plate 4.6 and Figure 4.8, is comprised of a composite cross section, with puddle core type zoning in the lower half of the dam and zoned earthfill in the upper half. The upstream half does have a sandy gravel zone downstream of the core, which may act as a filter.

Plate 4.6 : Stirling Dam

However, our experience with other dams of similar age and zoning in Victoria is that these sandy gravel zones were only transition zones and not filters. Typically these transition zones were built of lower quality material than would be required by modern standards for a filter. Similar comments have been made by Graeme Bell as independent reviewer of the preliminary design of the Stirling Dam upgrade works:

> *The proposed raising includes the construction of a riprap and gravel bedding. Other than these two zones, the dam will essentially remain as a homogeneous earthfill dam, at least in its upper half (the dam has a thin 'pug' core in its bottom half). I say "essentially" here because, although the dam has an outer stone fill zone, I have seen no data on the latter that would convince me it might provide some protection against piping. Experience from two dams in Victoria, built just a little later than Stirling,*

> *has shown that similar "sandy gravel" zones were basically impervious soils with some gravel-sized particles in them.*[28]

URS completed a detailed risk assessment of these two dams in Victoria. Based on those studies, one of these dams has already had major upgrade works to reduce the piping risk owing to deficient filters, and the other is programmed for major remedial works. The preliminary upgrade works for Stirling Dam do not currently address this potential deficiency, and we recommend a detailed assessment of piping potential be performed including sampling of the filter zone to evaluate its ability to act as a compatible filter. We understand that this assessment is already underway.

The main embankment of Logue Brook Dam shown in Plate 4.7 and Figure 4.9 is deficient compared to standards criteria because the chimney filter does not extend to Full Supply Level. The saddle dam shown in Plate 4.8 is also deficient in that it has no chimney filter, only a toe drain. These deficiencies increase the risk of piping through the dam under normal, earthquake and flood loading conditions. The historic performance method used by Geo-Eng to estimate the probability of piping failure is unable to take account of the increased risk posed by a filter that is not fully intercepting. A more detailed assessment of the piping potential should be performed for Logue Brook, however, we anticipate such an assessment is likely to indicate a low piping risk.

[28] Unisearch (2002) *Stirling Dam Upgrade Works – Stage 2 Preliminary Design Independent Review by Graeme Bell*, January.

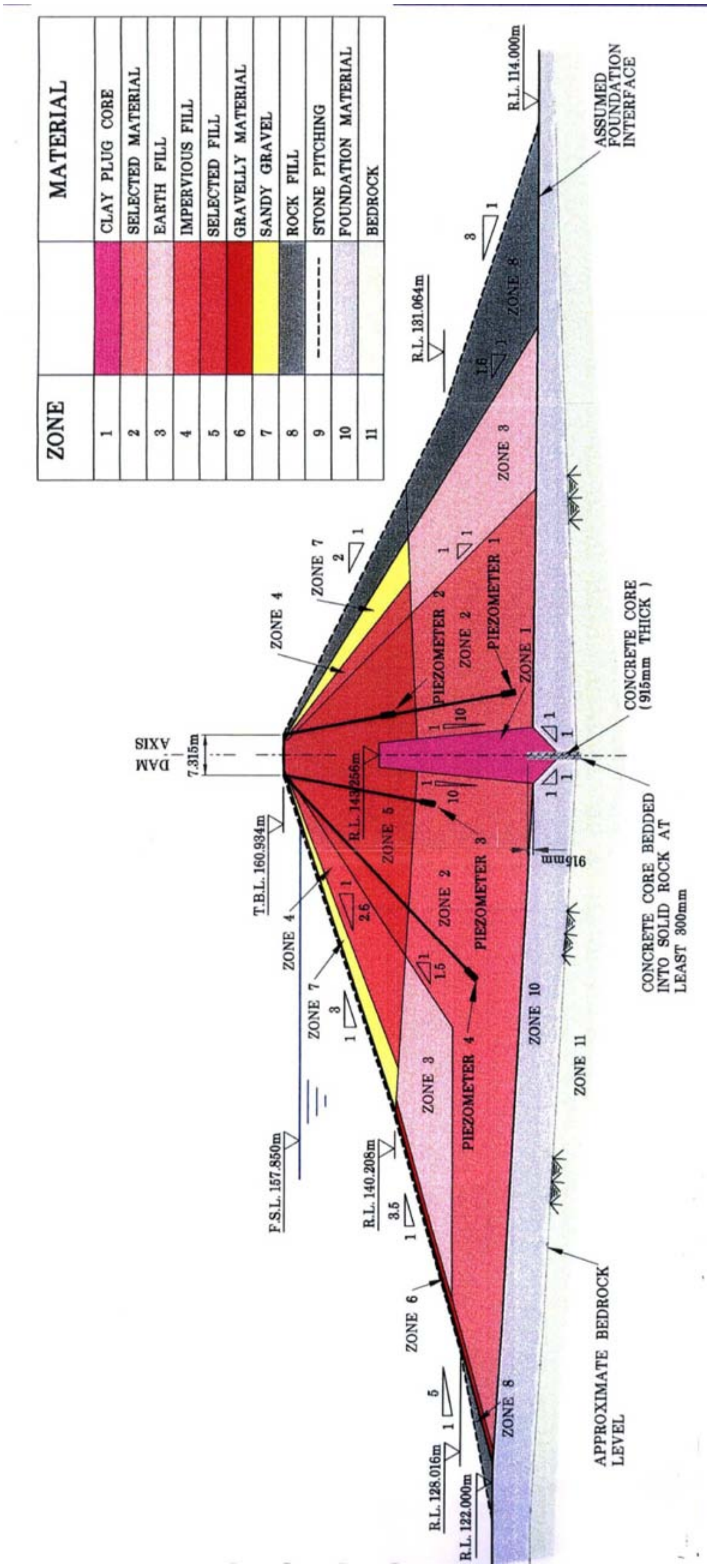


Figure 4.8 : Stirling Dam Section

Plate 4.7 : Logue Brook Dam Main Embankment

Plate 4.8 : Logue Brook Saddle Dam

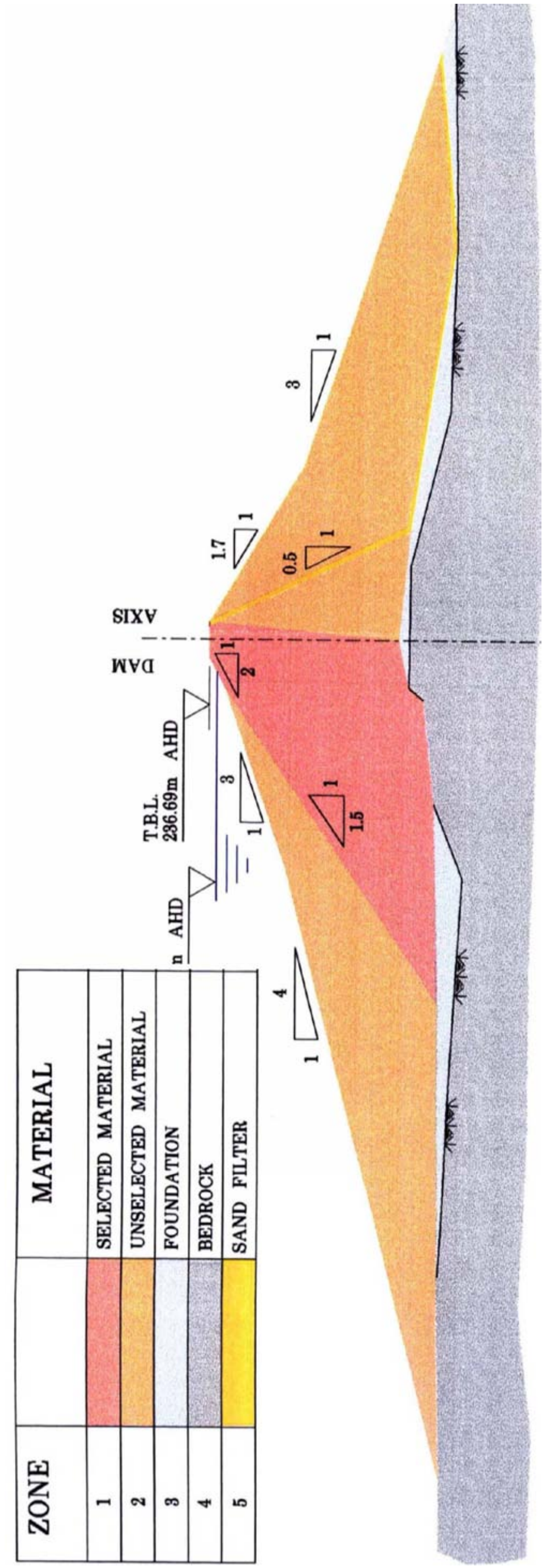


Figure 4.9 : Logue Brook Dam Section

4.3 STABILITY – EMBANKMENT AND CONCRETE DAMS

4.3.1 DESIGN CRITERIA

ANCOLD Guidelines[29] provide the following criteria for the factors of safety for the stability of embankment dams:

Downstream slope, steady seepage	FS = 1.5
Upstream slope, instantaneous drawdown:	FS = 1.25 to 1.3

4.3.2 WAROONA DAM

The studies by Geo-Eng concluded Waroona Dam does not possess an adequate margin of safety against downstream slope stability failure under steady seepage conditions. However, the assessment of current conditions appears to be based on relatively conservative assumptions for the selection of shear strength parameters and phreatic conditions. The marginal factor of safety values of about 1.07 at STA290 computed by Geo-Eng is not consistent with the survey monitoring data, which are indicative of normal deformation behaviour for a stable dam. The use of residual shear strengths for the foundation soils would certainly be conservative, whereas while fissuring is probably present in the residual soils, the orientation of such fissuring is unlikely to be disadvantageous for shear surfaces passing through the foundation. The parameters recommended by the 1999 Review Panel report, which are based on peak shear strengths, may be a more appropriate best estimate for the foundation soils.

Stability analyses have been performed as part of this review to gain an understanding of the sensitivity of the analysis to the design assumptions. These have been performed using the commercially available computer program SLOPE/W Version 4.2 adopting the Bishop slip circle method. The section at STA290 (located on the left abutment) was selected for analysis as this section yielded the lowest factor of safety in the Geo-Eng analyses and also has the highest measured pore pressures in the foundation. Pore pressures in the embankment and foundation were modelled by applying two different piezometric surfaces based on measured pressures when the reservoir was at FSL (RL 211), one applied to the embankment materials and the other to the foundation materials. We understand that one recent piezometer BH9/00 installed in the downstream shoulder has never been subjected to FSL, so another case was added to elevate pore pressures in the embankment by 4m. Analyses have been carried out for the following cases:

- Case 1 – Foundation shear strength parameters based on Geo-Eng assessment (c'=0 kPa, phi'=26 degrees) and measured phreatic surfaces;
- Case 2 – Foundation shear strength parameters based on 1999 Review Panel (c'=10 kPa, phi'=32 degrees) and measured phreatic surfaces; and

[29] ANCOLD (1969) Current Technical Practices for Design, Construction, Operation and Maintenance of Large Dams in Australia.

- Case 2A – Case 2 strength parameters with measured embankment phreatic surface elevated by 4 m.

The parameters for the embankment soils were assumed to be the same as the Geo-Eng analysis (c' = 5 kPa, phi' = 32 degrees). Table 4.3 summarises the minimum FOS for the critical shear surface for the two cases. Plots showing the location of the critical shear surfaces and analysis parameters are provided in Figures 4.9 and 4.10 for the two cases.

Table 4.3 : Summary of Static Stability Results, Cross Section STA290

Case	Foundation Shear Strength Parameters		Factor of Safety (Geo-Eng, 1999)	Factor of Safety (Current Review)
	c' (kPa)	phi' (degrees)		
1	0	26	1.07	1.40
2	10	32	-	1.63
2A	10	32	-	1.52

The results for Case 1, summarised in Table 4.3, indicates a higher factor of safety than the Geo-Eng analysis for the same shear strength parameters. The reason for this difference is related to the assumed pore pressures in the downstream shoulder of the embankment and foundation. The phreatic conditions adopted by Geo-Eng are not provided for this section in the Design Review report, but according to Bob Wark, they represent worst case conditions with elevated pore pressures, especially at the toe of the embankment and foundation. We confirmed that similarly low factors of safety using the adopted strength parameters would be indicated by the URS model if relatively high pore pressures were assumed to exist within the downstream shoulder (refer to Figure 4.11). We understand that some of the pore pressures used by Geo-Eng were extrapolated from actual measurements to represent worst case conditions with the drainage system failing to control pore pressures. Interestingly, with pore pressures controlled and best estimate shear strength assumptions adopted in Cases 2 and 2A, the factor of safety satisfies engineering standards.

The construction of the proposed downstream berm provides downstream weighting and increases stability even with elevated pressures, and in essence provides another level of defensive design to the upgraded foundation seepage collection system and upstream blanket. The downstream berm also provides a means for raising the dam to achieve the required flood capacity and providing a modern downstream filter. According to Bob Wark, it was essential that the design provide reliable stability even if one element of the design did not function as intended.

Figure 4.9 Waroona Dam, Current Study Stability Analysis (Using Geo-Eng Foundation Shear Strength Parameters)

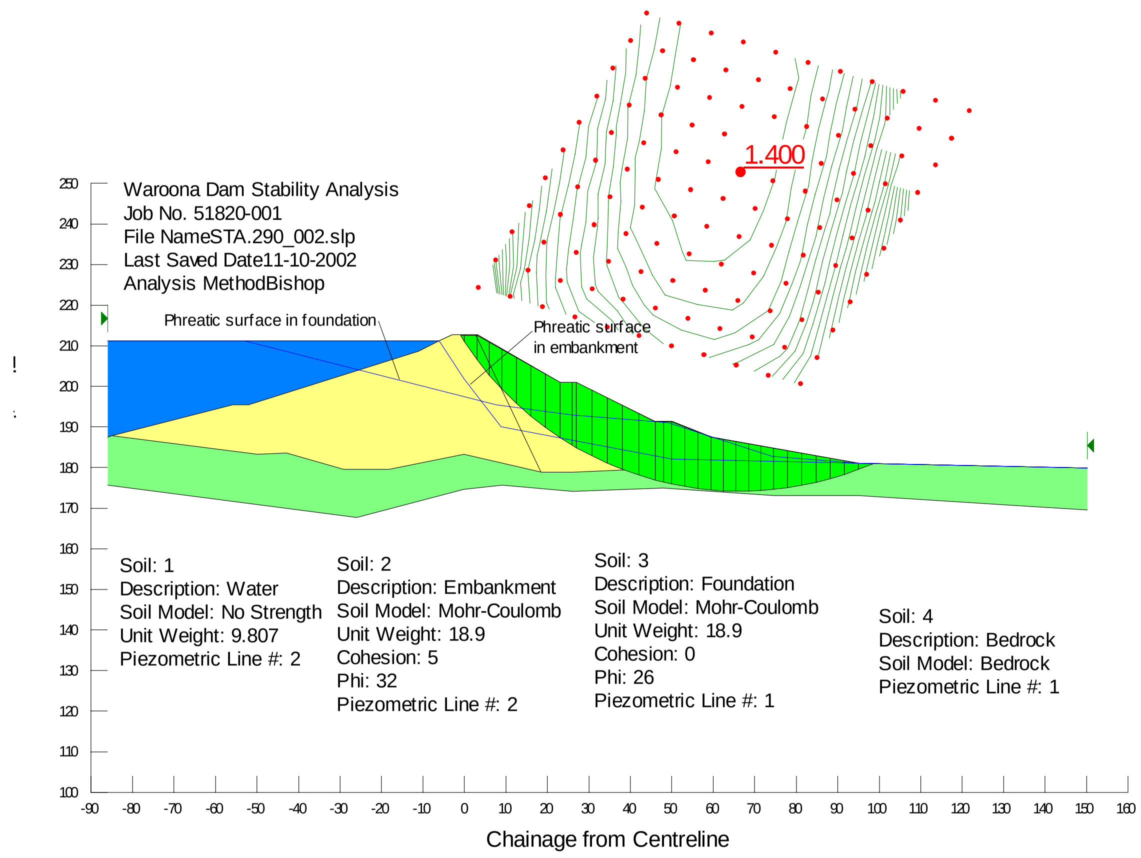


Figure 4.10 Waroona Dam, Current Study Stability Analysis (Using Review Panel Foundation Shear Strength Parameters)

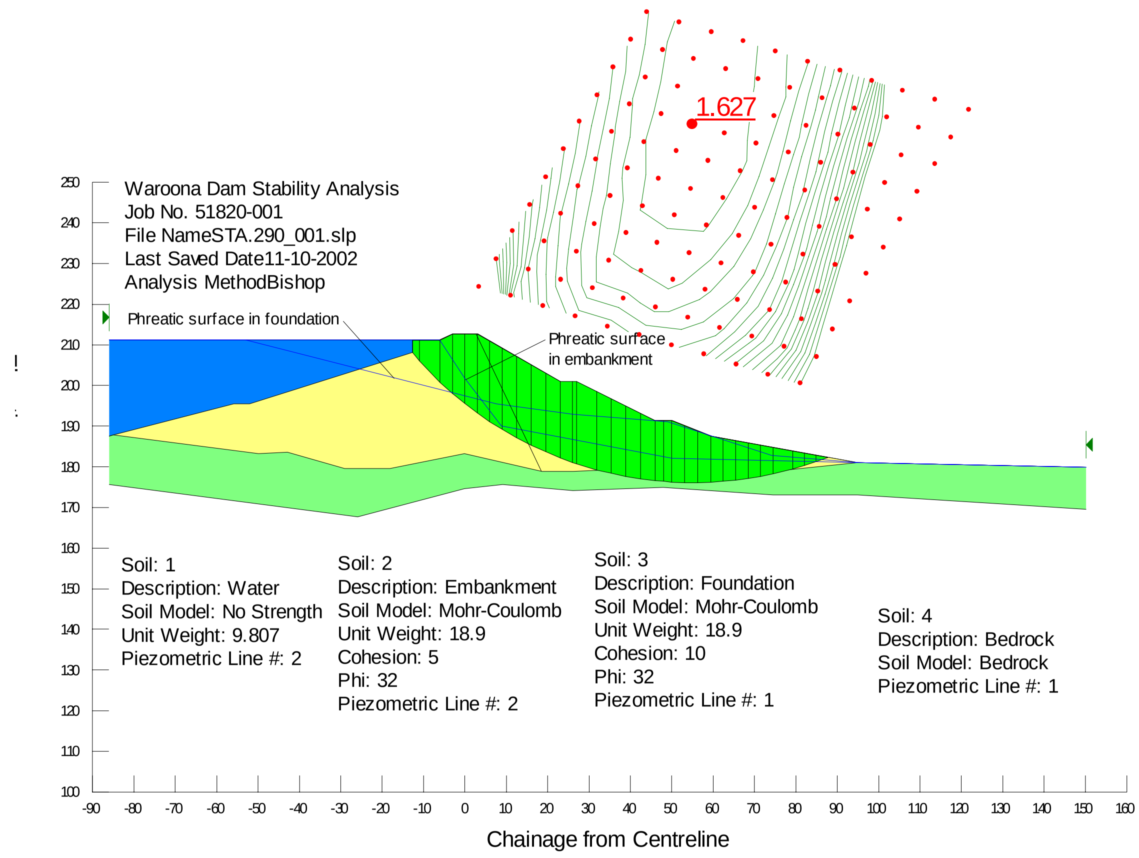
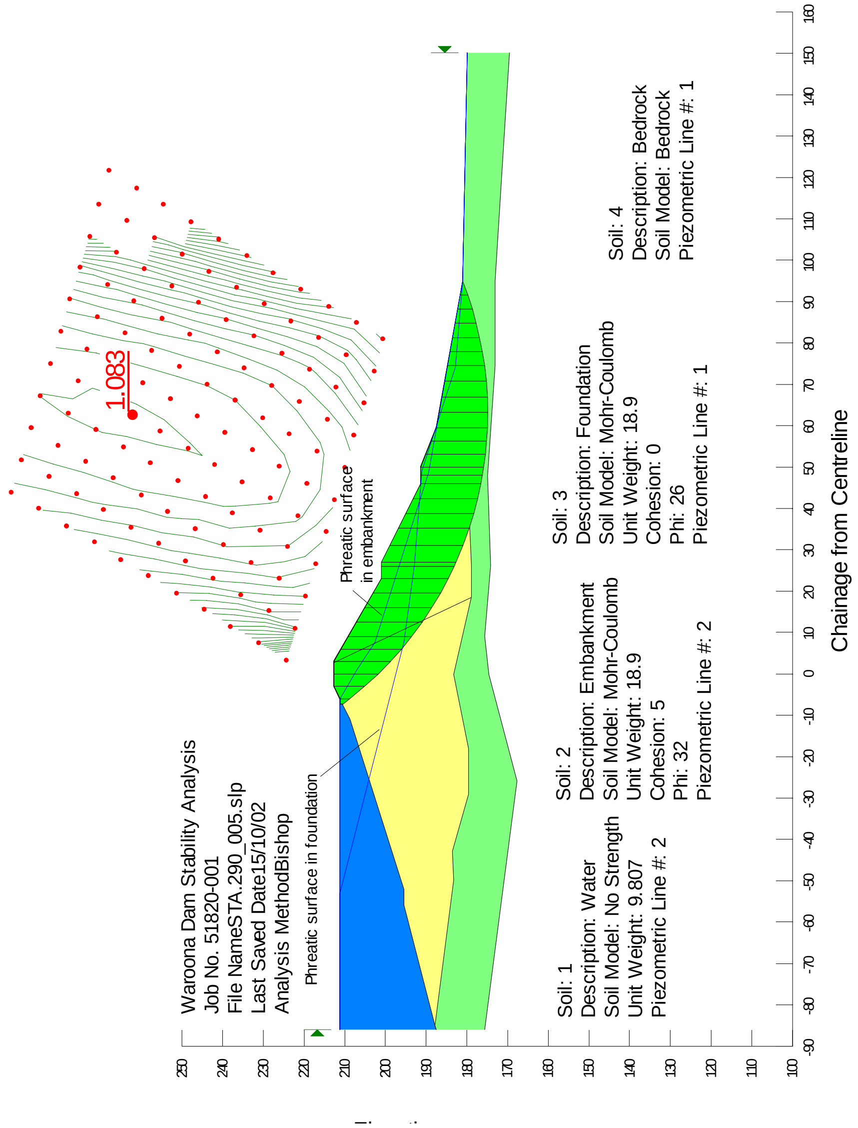


Figure 4.11 Waroona Dam, Current Review Analysis (Influence of High Pore Pressures in Embankment)



4.3.3 STIRLING, LOGUE BROOK, SAMSON BROOK & DRAKESBROOK DAMS

The methodology, assumptions and conclusions for the stability assessments carried out as part of the Design Review studies for the other embankment dams (Stirling, Logue Brook, Samson Brook and Drakesbrook Dams) appear to be based on sound engineering principles. Except for Drakesbrook Dam, the factors of safety obtained in those assessments show the dams conform to engineering standards for downstream stability under steady state seepage conditions. At Drakesbrook Dam, the computed unacceptable factors of safety seem reasonable given the elevated phreatic conditions in the downstream shoulder indicated by the piezometers and the large deformations the dam has experienced in the past. The risk that pore pressure conditions could rise leading to downstream instability is a concern and should be dam safety priority. Fortunately, the upgrade to reduce piping and instability risk may be relatively straightforward being comprised of replacing the deficient core above the puddle that has been added progressively as the dam has settled.

4.3.4 WELLINGTON DAM

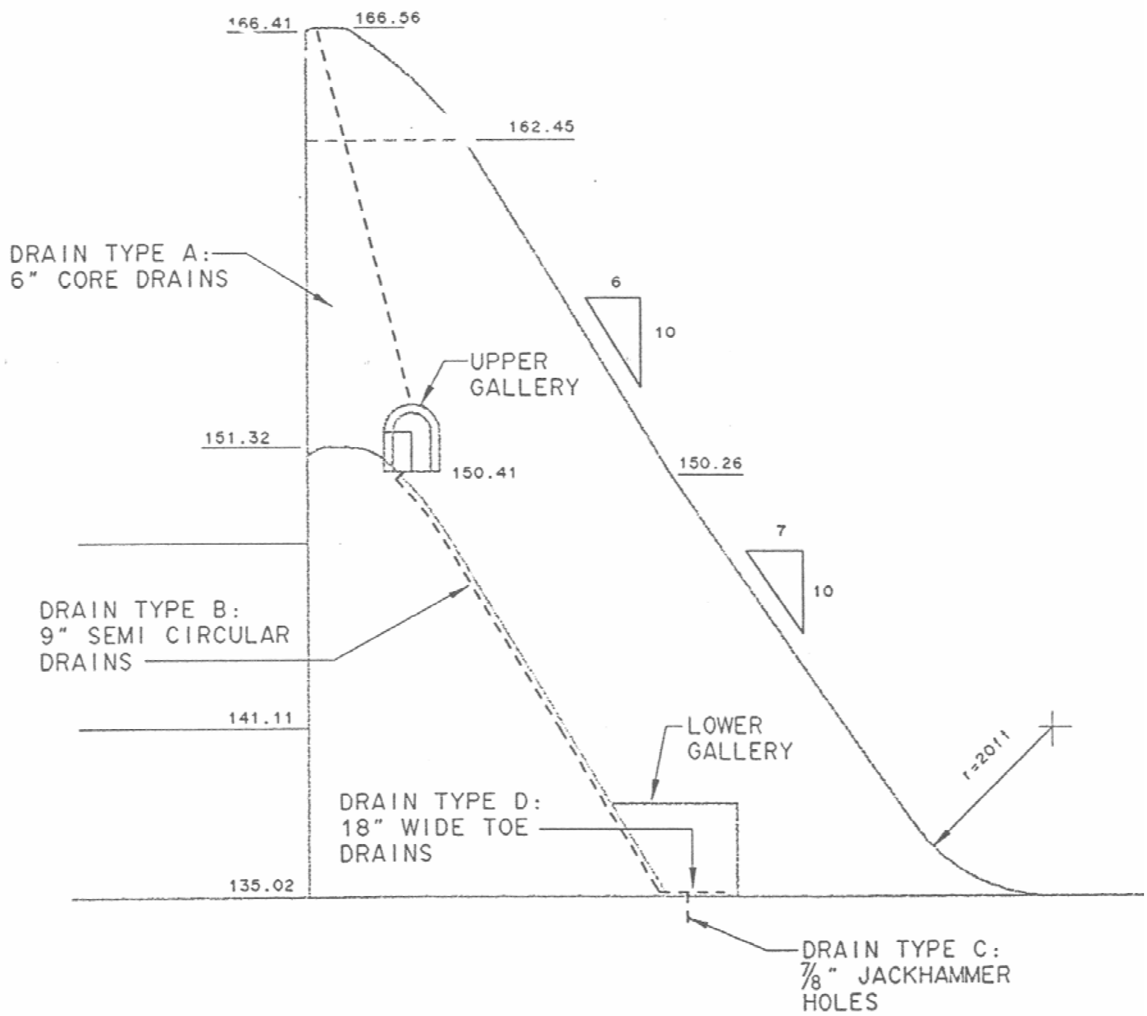
The static stability of Wellington Dam shown in Plate 4.8 and Figure 4.12 has been assessed by Geo-Eng and is reported in the report "Wellington Dam Safety Review" dated February 2002. The methodology and assumptions adopted in the stability analysis appear reasonable and are based on sound engineering principles. The significant finding of that study is that the stability of the dam would be marginal under a flood loading with an AEP of approximately 1 in 1,000. Furthermore, the estimated loss of life in a sunny day failure would be 550 and in a flood, 175, making Wellington an extreme hazard dam.

There was significant discussion on the conservatism of strength and uplift pressure assumptions used in the analysis. Using conservative values, the dam should fail under a flood level of between RL 166.7 to RL 167.8, which was actually experienced in 1964 without signs of distress. Bell points out in his review that using more realistic strengths, the dam would fail at a flood level of RL 168.6. Regardless, even with less conservative parameters, the imminent failure flood AEP of 1 in 1,000 is far too low for an extreme hazard dam which should handle the PMF with an AEP of at least 1 in 1,000,000.

There are several concerns with the stability of the dam:

- cracking through the original dam;
- disadvantageous joint orientation in the foundation rock (Plate 4.9);
- cracking at the base of the original dam (Plate 4.10); and
- AAR raising and rotating the crest upstream (Plate 4.11).

Figure 4.12 : Wellington Dam Section



We endorse Geo-Eng's recommendations for reducing the risk in the short term, which include drain cleaning, increased instrumentation and increased frequency of measurements. However, given the relatively high risk of failure of the dam under flood conditions even after the drains are cleaned, consideration should be given to the implementation of additional measures to further reduce the risk in the short term such as those recommended by Water Corporation's reviewer, Graeme Bell. These are reported in his notes prepared after the 30 May 2000 briefing and, as well as drain cleaning, include:

- developing a preliminary emergency preparedness plan with some early warning systems defined;
- deepening the existing foundation drainage curtain; and
- lowering the present operating FSL.

Plate 4.8 : Wellington Dam

Plate 4.9 Disadvantageous joint orientation in foundation rock

Plate 4.10 Cracking at base of original dam

Plate 4.11 Minor AAR Cracking on Downstream Face

4.4 OUTLET ASSESSMENTS

The primary dam safety issues associated with the outlet works include:

- access to operate guard gates and valves during an emergency;
- seismic stability of outlet towers;
- piping along unprotected conduits; and
- deterioration of conduits leading to potential leakage and collapse.

Of the four, the first two issues are significant for Waroona and Logue Brook because the access ladders are no longer present and the seismic stability is marginal (Plate 4.12). Seismic stability of the tower at Stirling (Plate 4.13) is also a concern. Seepage has been observed along the conduit at Samson Brook, but the flow is very small and currently not a concern (Plate 4.14). Deterioration of the cast iron conduit at Drakesbrook is a concern.

An important driver to upgrade the towers at Waroona and Logue Brook is normal operations and maintenance.

Plate 4.12 : Waroona Outlet Tower

Plate 4.13 : Stirling Outlet Tower

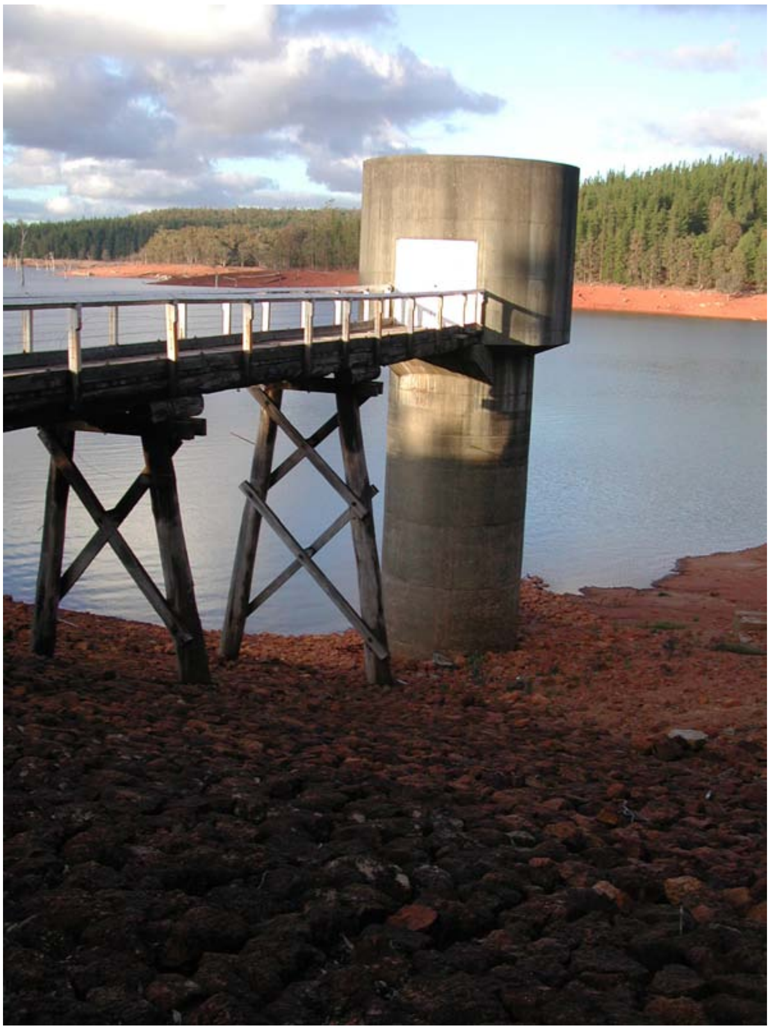


Plate 4.14 : Minor Seepage Along Conduit at Samson Brook

4.5 CONSEQUENCE ASSESSMENT (BREAK MODES, DAMAGE PATH, LOSS OF LIFE)

4.5.1 GENERAL

Guidelines on the procedures to be used to assess the consequences of dam failure are provided by ANCOLD (2000b). These guidelines are designed to provide input on consequences for risk assessment studies, and also input into the process for establishing priorities for dam safety management. Like other guidelines provided by ANCOLD and the Institution of Engineers, they are not intended to be prescriptive, and variation by appropriate experts is encouraged to ensure that all key factors are considered in the most appropriate manner.

A consequence assessment is the process used to identify all the potential consequences of dam failure, including loss of life, direct and indirect economic costs, social disruption, and environmental degradation.

After the consequences have been identified, a Hazard Category can be allocated to the dam. The categories are based on the severity of the potential damage and loss, in conjunction with the population at risk. Hazard categories are determined for "sunny day" failure conditions (associated with, say, internal erosion of embankment dams or the sliding and overturning of gravity walls) and also for flood failure conditions. It is usual to estimate the incremental consequences of dam failure, that is the additional loss or damage caused by dam failure compared with the event occurring without dam failure. There is some legal doubt as to the relevance of incremental consequences, and so more recently the trend has been to evaluate both the total and incremental consequences.

This review has concentrated on the information provided in a series of consequence assessment reports prepared by Water Corporation (one for each dam). In the case of life-loss estimates, the information contained in the reports has been superseded by later calculations, and the spreadsheets used to undertake the analyses were examined directly.

The following section summarises the main conclusions from the review of consequences.

4.5.2 DAMBREAK ANALYSIS

Dambreak analysis examines the impacts of dam failure following a breach of the dam wall due to overtopping by floods or by piping failure.

Estimation of the depth and extent of flooding arising from dam failure was undertaken using the BOSS DAMBRK model. This one-dimensional model is generally appropriate for the dams that were investigated. Consideration could be given to the use of a twodimensional model such as RMA-2 or MIKE21 for the floodplain below Wellington Dam as discussed below.

The cartographic base and location and frequency of the cross sections for the studies appears to be generally reasonable. From the discussion of the channel and cross-section division it appears as if there has not been any storage assigned to the floodplain. A large portion of the broad floodplains in the lower reaches of the rivers involved could be expected to be primarily storage, which does not contribute to the conveyance downstream of the flood flow. This could lead to a significant underestimation of the flood depths and extents. It is unlikely to change the location of the boundaries between high, medium and low forcefulness of the water in most locations, despite the lower conveyance area increasing the elevation and possibly the velocity of the water.

The adopted breach parameters generally appear reasonable and the sensitivity analyses gave an indication for the uncertainty in results for the key parameters. Without detailed consideration of the embankment conditions it is difficult to comment further on the appropriateness of adopted breach parameters.

The downstream boundary condition was not discussed. This could have an appreciable effect on the water levels if PMF is associated with a storm mechanism(s) that would cause a storm surge. If this has not been included then consequences could be underestimated as the level and extent of inundation may be underestimated. On the positive side, there may be lower velocities and longer warning times.

In a number of the reports there are comments that the railway line would have an insignificant impact on the assessment. The appropriateness of this assumption is difficult to assess without further information, though it would be expected that the final results are unlikely to be overly sensitive to this assumption. The embankments may provide some relief from high force waters and hence influence the damage assessment and the estimates for potential loss of life (PLL). Consideration could be given to this if a more detailed risk assessment were to be undertaken, or if it was suspected that differences in exposure could influence the relative rankings across the portfolio of South West Dams.

The method used to estimate coincident flooding in the Waroona catchments is overly simplistic. For the dambreak events the contribution from adjacent catchments is ignored, and for the natural flooding events conservatively high estimates have been adopted. These assumptions would lead to an underestimate of both the incremental and total consequences. A more suitable, but still simple, procedure based on joint probability concepts is documented in Book VI of ARR99, though other procedures could be developed.

4.5.3 Estimation of Life Loss

Life loss has been estimated using a procedure developed by Graham (1999). This method is recommended by the ANCOLD (2000) guidelines. The method recommends fatality rates based on the flood severity, warning time, and a measure of whether people understand the severity of the flooding. It is based on an empirical relationship derived from a relatively large data set of approximately 40 floods, many of which were caused by dam failure.

The outputs of the hydraulic model are used to determine the degree of flood severity at various locations downstream of the dam. This is combined with information on the population at risk, and the likely loss of life is then estimated using the empirical relationships proposed by Graham. It should be stressed that there is considerable uncertainty with this approach, and while this area continues to provide a fertile area of research, at present it is generally accepted that there is no better method.

Unfortunately the most current estimates of life loss have not been formally documented, and the following comments are made on the basis of reviewing the spreadsheets directly. The spreadsheets are reasonably complex and they are not structured in a particularly logical manner. They are thus quite difficult to audit. Some tentative observations arising from the calculations include:

- the criterion used to specify "High" flood severity appears to differ from that specified by Graham;
- high flood severity is quite a rare category and it would appear – surprisingly – that it occurs at least at one location downstream of most dams;
- some of the VLOOKUP functions used to calculate the population at risk return negative values, which are carried through to erroneously reduce the summed loss-of-life estimates; and,
- one population centre only can be considered for each dam – it is unclear how appropriate this assumption is in terms of warning times.

Aside from the above comments, there are two main issues with the manner in which the life loss has been estimated, namely the consideration of the:

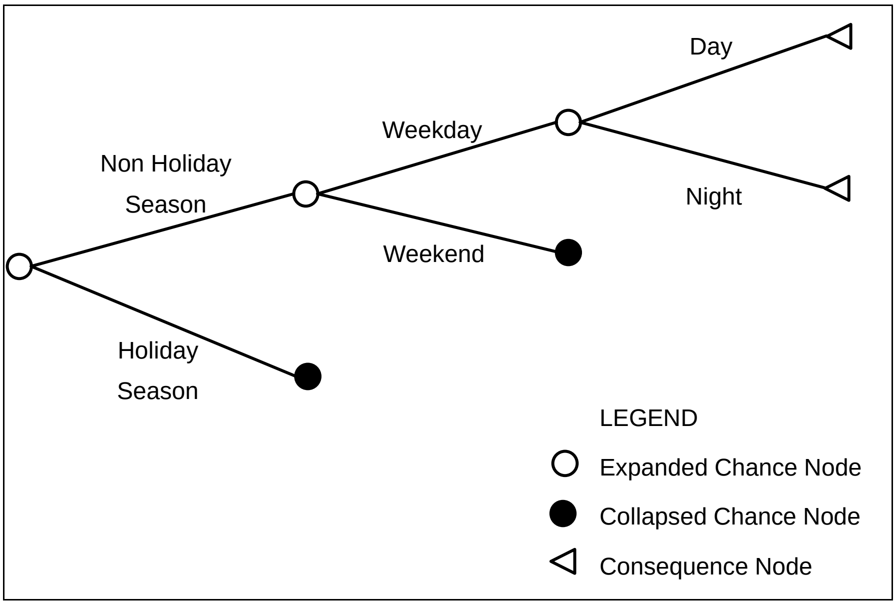
- diurnal and seasonal variation in the population at risk (PAR); and
- estimation of incremental life loss.

With regard to the former point, Graham (1999) recommends that a loss-of-life study should include a day and night category for each flooding scenario investigated, since the amount of warning provided and the number of people exposed to dangerous flooding is significantly influenced by the time of day. If seasonal variation in the population at risk is important, then the analysis should also include separate seasonal estimates of life loss.

It would appear from the spreadsheets provided that the total life loss estimates were calculated by weighting the population at risk by an exposure factor. Thus, diurnal variations in weekday and weekend populations were simply factored by the proportion of time relevant to each category. It also appears that the number of recreational users at the dam was not expected to vary seasonally. For example, for Waroona Dam it was assumed that a recreational population of 50 was present all year round (though this was differentiated between weekday and weekend exposures), and since the majority of these were assumed to be located a short way downstream of the dam, this population contributes to an appreciable proportion of the estimated life loss.

As discussed in Hill *et al* (2001[a]) the calculation of the weighted loss of life external to the event tree can yield misleading results, and it is more appropriate to include the different exposure conditions as branches in the event tree (as shown in Figure 4.13). This is particularly the case for seasonality as the probability of a specific flood occurring in a given season is markedly different to the likelihood based solely on the length of the season being considered. If the PAR estimates are weighted using the exposure factors then the range of PARs that can occur under variations in exposure cases will not be displayed in the portfolio risk results. The provision of an average PAR estimate can distort the understanding of the scale of potential life loss. It also makes it more difficult to meet ANCOLD societal risk criteria, that is the line on an F-N plot will intersect higher diagonals on the plot when a weighted average PAR is used than when each PAR and its exposure factor are separately considered. By considering separate PARs for each exposure case, one can sometimes identify non-structural risk reduction alternatives, which might otherwise be overlooked, such as limiting recreational populations.

Figure 4.13 : Example of exposure time subtree



Estimates of the total PAR were determined by conducting field surveys in conjunction with aerial photography and census data. While these represent appropriate sources of information for this purpose, it is noted that PAR estimates for Waroona Dam collected by Harvey Water during the course of this review are appreciably lower than that used in the original studies. It is suggested that the sources of this discrepancy be investigated to determine whether or not PAR estimates for the other dams need to be revised.

Estimates of *incremental* life loss of dam failure was determined by subtracting the estimated loss of life associated with Imminent Failure Floods (no failure) from that associated with dam failure. There are two problems with this. Firstly, incremental life loss for flood-induced failures should be estimated as the difference between estimates for the failure and no-failure cases for the same AEP floods. Differences in depth and other flooding characteristics, including travel time, in the area that would be inundated for both failure and no-failure events with the same AEP, would be overlooked if only the band of additional inundation (above the Imminent Failure Floods) were focussed on. Adoption of this approach would lead to the estimates of incremental life loss being overestimated.

The second problem with the incremental life loss estimates is that Graham’s method is used for both failure and non-failure cases. While Graham’s method is based on case studies involving of dam failure as well as “flash floods”, the results for the latter are associated with very short warning times. Thus, unless the non-failure cases can be considered to be flash floods the method is likely to overestimate the life loss, and hence underestimate the incremental life loss.

From the results contained in the spreadsheets the majority of the life loss estimates associated with normal floods represents only a small proportion of the dam-failure cases. The one exception to this is Stirling Dam, where the incremental life loss is around two-thirds that of the total. The catchment area for Stirling Dam is 250 km^2, and thus it is likely that incremental fraction is an underestimate of the true value as the warning times for normal floods from a catchment of this size are likely to be longer than that considered by Graham.

Given the legal uncertainty surrounding the defensibility of liabilities being restricted to incremental losses it is suggested that in the future estimates of both *total* and *incremental* estimates be provided.

Lastly, it is not clear whether any consideration is being given to identifying the probability of life loss for the *individual* at greatest risk. For dams with low estimates of life loss individual risk criteria tend to be more stringent than societal risk criteria (i.e., the tolerable level of risk associated with the loss of an identified individual may be lower than society’s aversion to multiple fatalities), and thus it is necessary to present the results for both sets of criteria.

4.5.4 ENVIRONMENTAL CONSEQUENCES

In each case, the environmental impacts of dam failure were not included in the consequence assessment. As stated in the foregoing section, this was deemed appropriate as the hazard classification of the structures were generally dominated by life loss considerations. However, the environmental consequences from such huge events can be substantial and can provide additional justification for the level of works subject to the ALARP principle. Further, "triple bottom line" accounting is becoming increasingly important in justifying public expenditure.

Hill *et al* (2001a) identify a method for assessing environmental effects which includes the following environmental components:

- riverine systems;
- wetlands;
- terrestrial systems;
- aboriginal and heritage sites;
- threatened species; and,
- parks and reserves.

Alternatively, ratios can be developed and applied that provide a quantitative indication of the environmental damage that is likely to be sustained.

4.5.5 DAMAGES ASSESSMENT

The consequence assessment was primarily aimed at determining the hazard rating of each of the structures. In general the potential loss of life, PLL, dominated the hazard classification and so in many situations either no assessment was made or a coarse estimate was judged to be appropriate as the inclusion or refinement would not have altered the overall classification. Since these reports there has been some revision of the PLL. The comments below provide comment as to where further work would be justified and / or change the relative priority of the structures in regard to upgrading.

Direct damage costs have been obtained from a number of sources for each study. For different dams, different items' types of damages were quantitatively assessed depending on whether they were considered to be major or not. Hence there is some difference in the items that make up the total direct consequences. For instance, for PMF failure the agricultural direct costs were estimated as follows:

- from ABS figures to be $11.2M for Wellington Dam;
- from ABS figures to be $8.4M for Samson Brook Dam;
- from ABS figures to be $180M for Stirling Dam;

- from ABS figures to be $11.7M for Logue Brook Dam. This was estimated in Appendix D2 but was *not* included for some reason in the total calculated in Table 5.3 of its report;
- for Drakesbrook Dam agricultural direct costs were judged to be minor and not assessed; and
- for Waroona, these costs were not quantitatively estimated although qualitatively judged to be “major”.

The estimates of direct damages appear to contain a mix of direct and indirect costs, and exclude a number of direct costs such as damage to farm sheds, machinery, fencing etc. In some cases, the direct agriculture costs did include an estimate of the lost future production. This was estimated to be 1-3 years in most cases, though this would appear to be an optimistic estimate for replacing a storage and having it meet demand.

Indirect costs have not, in general, been assessed. Hill *et al* (2001a) found that these costs may in fact far outweigh the direct costs. This possibility was acknowledged in the reports, though not quantified. Consideration should be given to estimating indirect costs such as:

- deployment of emergency services;
- dislocation costs from severed road and rail links (can be significant if there are important freight links);
- telecommunication infrastructure; and
- provision of temporary services where large populations are involved (the reinstatement of permanent water and wastewater services can take months or years, and temporary arrangements are very costly).

For Waroona Dam it was speculated that the losses suffered by a refinery cut off from gas without warning could exceed $500 million, though this was not investigated further. While it was acknowledged that intangible damages are potentially important, no effort was made to estimate them.

In general it is considered that the economic consequences of dam failure have not been undertaken in a consistent nor particularly thorough manner. The impression created is that the estimate of damages has not been given much importance as the hazard rating is dominated by life-loss considerations. While this may be true, the use of damage estimates that may be inaccurate or obtained in an inconsistent manner will undermine efforts to identify the optimum risk-reduction pathway across the whole portfolio of dams, even though a standards-based fix is deemed appropriate.

It is recommended that an economist with experience in this type of assessment be included in the estimation of financial/economic damages. This is particularly the case with respect to indirect and intangible damages as these factors could impact substantially on the prioritised ranking of remedial works.

4.5.6 SUMMARY

In summary, the review of the consequences reveals:

- the general approach adopted for dambreak analysis is appropriate, though there are some aspects (primarily related to floodplain storage and the modelling of internal and external boundaries) that could be further investigated and/or improved upon;
- the procedure used to estimate the loss of life has not been formally documented and this situation should be rectified. Inspection of the calculation spreadsheets indicate the presence of some (minor) calculation errors and the criteria used to specify high flood severity appear to differ from published procedures. In addition, it is suggested that the manner in which the different exposure factors are treated could be improved upon, and anecdotal discrepancies in estimates of the population at risk should be investigated;
- the environmental impacts of dam failure were not included in the consequence assessment. Such impacts can be substantial and can provide additional justification for mitigation measures; and
- in general the economic consequences have not been undertaken in a consistent nor particularly thorough manner, and it is suggested that improvements to this component will help identify the optimum risk-reduction pathway across the portfolio of South-West dams.

5 RISK MITIGATION STRATEGY FOR SOUTH WEST DAMS

5.1 PROCESS

Water Corporation currently utilises a process that compares favourably with current Australian best practice in dam safety management. The Corporation has adopted risk-based decision-making and a stated objective of eventually reaching compliance with modern ANCOLD dam engineering standards. It has utilised Professor David Bowles to review independently its portfolio risk assessment process. Water Corporation has formalised these objectives in a strategic plan, which is being progressively implemented across its 17 priority dams. It has reported to us verbally that this risk profile is constantly being updated as new information becomes available. Evidence of this is that the priority dams list has now grown to 21 dams. It now has a panel of engineering consultants including Geo-Eng from which to obtain engineering and design services and is no longer reliant on a single organisation. The Corporation has also utilised independent expert review.

To meet current best practice, Water Corporation may wish to enhance specific elements of its dam safety program, including:

- transparent expert review plus a mechanism to ensure resolution of outstanding issues;
- utilising detailed risk assessment techniques to update and refine its risk profile as design reviews and concept designs are completed for each dam. This may affect the prioritisation and urgency of works, and help support critical funding decisions;
- considering interim risk reduction works to achieve risk levels below the ANCOLD tolerability limit; and
- conducting stakeholder involvement exercises to provide communication and build consensus for risk prioritisation and works projects.

5.2 EXPERT REVIEW

Expert review of various stages of the dam safety management program is an extremely important and valuable means of validating the direction of dam safety activities by an expert or panel of experts not directly involved in the management or design of the facility. This review should provide an independent, auditable and transparent confirmation that the technologies, rationale and approach are unbiased and appropriate to the task, representing best practice. The peer reviewers should answer directly to the Board and provide a detailed report after each session, which is presented directly to the project team and Water Corporation management.

Expert reviewers should be selected not only for their technical expertise but also for their mature, broad-ranging experience with dam safety upgrade projects relevant to the current Water Corporation project. They should also have excellent consensus building and communication skills. Above all their reputation should be unquestioned, since their advice will carry so much weight with the Board and stakeholders.

Expert review should be carried out not just at the end of the project or to secure approval from the Board, but throughout the dam safety upgrade process. This provides sufficient time for the reviewers to become familiar with the project as it is developing and gives the project team time to respond and act on their recommendations before they become a problem. Expert reviewers can be used in the detailed risk assessment process, in the detailed design review and design process, with stakeholders, and during construction.

The expert review process needs to be transparent such that any recommendations provided in reports are fully responded to, so that the reviewer can eventually sign off on the project. Our review of the Waroona process suggested to us that several important recommendations made by Bell and Fell were not fully addressed at the time, especially pertaining to the urgency of the embankment upgrade works. The design team or Water Corporation does not have to accept every expert review comment or recommendation, but each issue must be formally addressed and resolved in subsequent documentation, and then signed off by the reviewer. We understand from Michael Somerford that all of the issues raised by Graeme Bell have been addressed and that Graeme has signed off on the final design.

5.3 DETAILED RISK ASSESSMENT

Quantitative risk assessment methodologies utilising event trees and expert panels provides Water Corporation with a powerful, transparent and legally defensible process by which to characterise, prioritise, communicate and manage its dam safety risk. Utilising the societal risk F-N curves has already provided a useful means to communicate risk to the review team, Harvey Water and the Water Corporation Board.

Detailed risk assessments take the preliminary risk assessment to a higher level of reliability by utilising the results of developing studies and engineering assessments to provide a strong basis for decisions. It has been our experience that detailed risk assessment may lead to certain issues being downgraded in terms of risk priority, but may just as well raise the priority of other issues. The important factor is that the risk levels are being refined with increasing understanding of the drivers of those risks.

We understand that Water Corporation has some reservations about detailed risk assessments conducted using expert panels and creating event trees for critical failure scenarios. Its concern is about the subjectivity of probability inputs into the event trees. In the past few years, this process has become relatively well developed and much more consistent and reliable. We now have robust and tested subjective probability guidance for those events with limited statistical basis, and powerful means to characterise uncertainty using Monte Carlo simulation. Furthermore, there are a growing number of dam practitioners in Australia and overseas who have become quite familiar with the process. New processes to utilise statistical databases of dam incident and failure experience are being used routinely. However, the most important advantages of detailed quantitative risk assessment is the ability to consider the entire inventory of dam safety issues consistently to provide a robust comparison and prioritisation. The process of creating event trees alone is highly valuable because it forces the panel to clearly de-convolute complex problems into understandable and quantifiable components. This process also aids in the development of risk reduction strategies, since their effects can be directly assessed in the event trees. Overseas, the Bureau of Reclamation includes expert panels and event trees as fundamental elements of their dam safety tool box.

The use of expert panels is crucial to the success of a detailed risk assessment workshop. The panel needs to represent expertise in the full range of dam safety issues being considered. Panel members usually include owner or designer representatives who provide direct knowledge of the dams. Operational expertise is also usually required. Facilitation is always useful to keep the panel on track and to achieve consistency.

Best estimate parameters should be used in detailed risk assessments to avoid burying levels of conservatism in the analyses. The potential impacts of lower bound properties should be explicitly evaluated and their impact considered in the risk assessment, but with the likelihood of those lower bound values considered. Load factors and other conservative design tools mandated by standards should be avoided. The key question is whether the real situation could cause a failure under various load combinations and whether certain sets of less likely conditions could lead to failure. Standards-based design tools would later be used for remedial works design to meet modern criteria, but not to assess risk levels.

We believe that in the case of Waroona, a detailed risk assessment would have affected the perceived urgency of the full scope of works. At the time of our review, the case for the full scope of works was not compelling. However, review of the recently provided additional information in an expert panel workshop would have helped us understand and strengthen the need for urgent works.

Water Corporation has questioned the legal defensibility of the QRA process. Although the process is widely used in Australia, the UK and US, it should never be used to define the final scope of remedial works. This must be based on achieving modern engineering standards. Until those deterministic standards are redefined, they represent the final target to be achieved by dam safety upgrade works.

5.4 INTERIM RISK REDUCTION

Water Corporation has established the means and process by which to set interim risk targets and strategy for each of its 17 priority dams. Interim risk targets acknowledge that it is impossible to achieve the desired modern standards at each dam in a short timeframe and therefore identify structural and non-structural measures that can be implemented over time progressively to reduce risk. Instead of going straight for a final standards-based upgrade at each dam, the highest value risk reduction actions are implemented first to reach agreed interim risk targets.

Interim risk reduction utilises key work already completed, including the portfolio risk assessment, design reviews and concept designs. The detailed risk assessments discussed above are used to quantify and refine the highest risks, and then assess the effectiveness of each risk reduction measure. Interim risk targets could include:

- **First Target** - Risks falling within the Intolerable range above 10^{-3} would need to be reduced below 10^{-3} with the highest urgency;
- **Second Target** - Risks falling within the ALARP region below 10^{-3} would be subject to the ALARP test. An interim risk reduction target could be set at 10^{-4}; and
- **Final Standards-Based Target –** Meet modern dam design standards.

These risk targets would be based on lives risk. Similar financial risk targets could also be set. The overall strategy to achieve these interim and final risk targets could then be presented to the Water Corporation Board and stakeholders for concurrence and approval.

For Waroona, a lower piping / stability risk established in a detailed risk assessment process might have made an interim risk reduction strategy more attractive. Assuming that the flood risk remained intolerable, perhaps the first interim risk reduction stage would have upgraded the spillway crest and discharge channel to the final configuration that without raising the embankment would increase the flood capacity to say an AEP of 1 in 50,000. The geotechnical risk would be managed in the interim with continued close surveillance and drain cleaning. The second stage would implement the full embankment and foundation upgrades, and raise the crest to handle the PMPDF. This would achieve the desired standards based fix.

We acknowledge that Water Corporation and its consultants believe that the piping risk and the flood risk at Waroona are both intolerable, and that an interim solution that does not reduce both of these risks would not be a prudent risk reduction strategy. We also understand that community consultation confirmed that a two-stage process where the reservoir is drawn down twice would be undesirable. So we can understand the utility of reducing the risk with a single project which achieves modern design standards would be preferred.

Regardless, we understand from the workshop, that interim risk reduction measures are being considered by Water Corporation for every dam safety upgrade project. The following examples were provided:

- the Serpentine Dam remedial works involves a staged upgrade of the spillway to the PMPDF. The first stage, completed in 2002, provides security up to the 1 in 100,000 AEP flood;
- interim measures were implemented at Waroona in 1997 including lowering the reservoir operating level, increased monitoring and emergency planning;
- similar interim measures are currently in place at Churchman Brook Dam whilst the remedial works are designed; and
- the current program included staged upgrades for Logue Brook, Drakesbrook and Samson Brook Dams.

We strongly endorse this process.

5.5 STAKEHOLDER INVOLVEMENT

Stakeholder involvement in the dam safety risk reduction process provides an effective means of communication of risk issues and soliciting input from those affected directly by the risk. Bringing stakeholders in to the process relatively early also provides ownership of the shared objectives and outcomes.

There is usually some concern about sharing risk information with a non-technical audience, with worries about detailed information being misunderstood or risk issues being overblown or used by adversarial parties. These concerns can be managed with an effective staged consultation process. Confidentiality agreements can be used to manage information flow. In fact, experience has demonstrated that stakeholders are usually quite willing to accept risk once it has been explained, it is understood and a risk reduction strategy is enunciated. Many community fears are often founded on poor information or the absence of a clear understanding of the issue.

Goulburn-Murray Water (G-MW) has adopted the most aggressive approach to date in Australia with stakeholder involvement in its dam safety program. They formed a Stakeholder Reference Panel appointed by the Board and comprised of members drawn from a wide variety of local and state governmental, farmer / irrigator and catchment authority bodies. This group met with the risk assessment team, and in particular had direct input to the consequence assessment team. They provided valuable input to the risk management process and provided a strong endorsement to the G-MW Board and its respective organisations. G-MW can now progress its risk reduction program aggressively and with confidence, knowing it is widely supported.

Another useful example is for a major tailings dam in the United States, which is located directly above a town. Studies conducted in the 1980s revealed significant risk of seismic liquefaction in a large earthquake and flow failure that would inundate a significant portion of the town. For years, the mining company chose to limit distribution of this information and attempted to find a cost-effective solution. Just before implementing a massive $150 million buttress project, they were convinced to take a more aggressive staged dewatering and slope flattening approach with open public consultation which demonstrated that the risk would be reduced progressively and affordably over a number of years. Out of the consultation process a reasonable compromise was reached where the houses closest to the impoundment were protected by a diversion berm. The solution was warmly received by the community and rapidly implemented. After years of dangerous inaction and angst by the company, a much simpler and cost-effective solution was implemented through stakeholder participation.

The cost and time required to conduct useful stakeholder reference panels and briefings should not be underestimated. Educating a group of non-technical stakeholders in complex risk issues requires site visits, technical briefings, workshop sessions, independent review meetings and management briefings. In the case of the recent G-MW stakeholder reference panel, this process took about six months and required investment from not only G-MW but also the stakeholder organisations.

6 THE COST BASE

The purpose of this chapter is to provide an understanding of the magnitude of the proposed costs as currently estimated and of what constitutes efficient and appropriate costs, i.e., what is the cost base.

The issues, arguments and judgements associated with the funding of efficient costs are considered in Chapter 7.

Water Corporation has provided initial estimates of the cost of safety upgrades for the six South West Dams. In the case of Waroona the cost estimates refer to the contracted costs for the works. Thus, the $20 million costing for Waroona has been taken as a firm figure, but for the other five dams the estimates must be seen as preliminary. (Chart 6.1 shows the estimated cumulative expenditure on the portfolio of South West Dams.)

The Corporation suggested that these preliminary costings have a ± 50% error margin but our technical advice and judgement suggest that the final figures are more likely to be higher rather than lower.

To translate these costs into bulk water prices, the Corporation has used an annuity formula based on a 6% return over 80 years. The application of this annuity is discussed in Section 7.7 below.

6.1 EFFICIENT COSTS

The first key step is to form a judgement on what constitutes the efficient cost base.

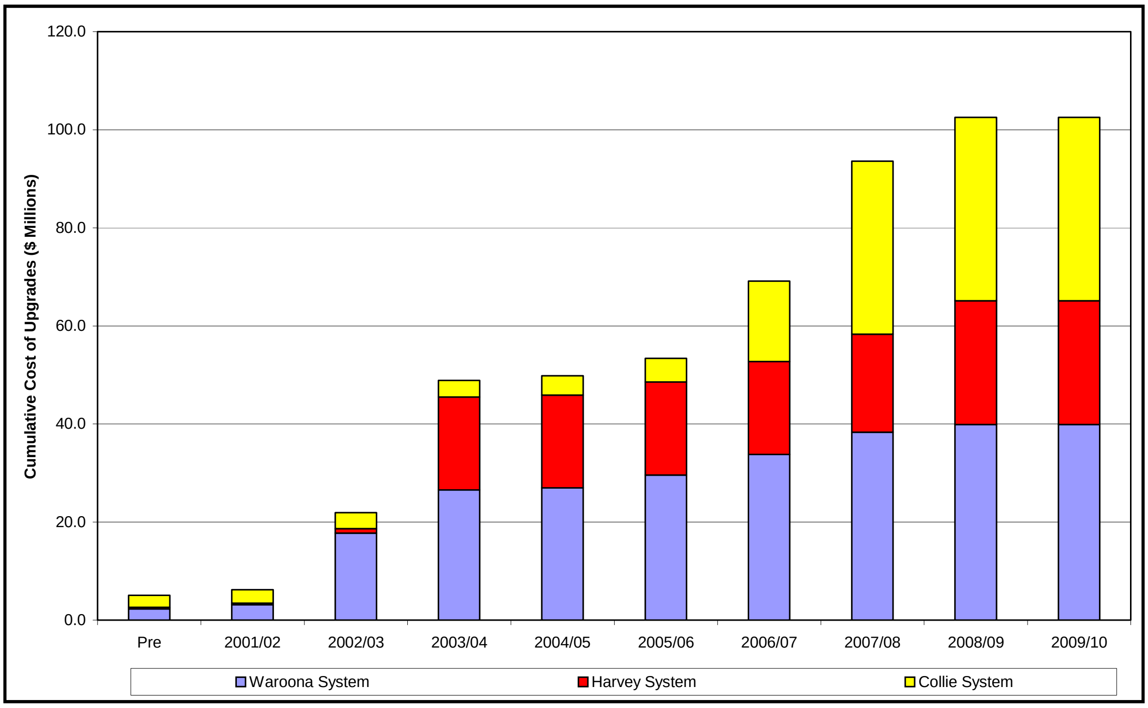
Efficient costs must be defined in terms of multiple dimensions, i.e., dealing with the right problem by the right strategy, the right infrastructure choices, (i.e., upgrade options), implemented at efficient cost and in the right timeframe and risk reduction pathway.

Consistent with the principles of economic regulation, prices paid for the service (in this case, bulk water) should be based on efficient costs leaving any cost inefficiencies to be borne by monopoly suppliers.

Efficient costs must be defined at a specified level of risk such as dictated by a standard or by the ALARP criterion. This is so because greater willingness on the part of the community and standard setters to accept and manage risk obviously lowers the level of efficient costs, and conversely.

Towards the conclusion of this review, Water Corporation reported that the contracted cost of the Waroona upgrades totalled $17.3 million rather than $20 million. We have not adjusted the detailed financial analyses to reflect this changed figure.

Chart 6.1 : Cumulative Dam Safety Upgrade Costs – South West Dams



6.2 SPECIFICATION OF ACCEPTABLE LEVELS & MANAGEMENT OF RISK

Levels of risk for Waroona have already been set by Water Corporation : contracts have been let.

However, the question arises as to whether the contracted/accepted levels of risk and priority of the works are appropriate when identifying the levels of cost relevant to irrigators. Indeed, this question is the nub of the Terms of Reference for this review.

We need to understand how levels of acceptable risk (standards/ALARP/other), approaches to managing that risk and the priority and timing of remedial works are set, particularly in the context of capital constraints and competing priorities, both within the dam safety programs and more widely within Water Corporation, and indeed, more widely within the Government.

6.2.1 FRAMEWORK FOR DECISION

It is useful to reiterate the framework for decision making on risk and risk management. First, in Western Australia, Victoria and South Australia, there are no specific government legislation or standards for dam safety. Therefore, the standards adopted for the reviews have been those prepared by ANCOLD, the Australian Committee of the International Commission on Large Dams.

Second, the need to upgrade major dams can arise from either a physical deterioration of an asset or a change in the industry safety guidelines. A change in safety guidelines does not mean that the dam is in imminent danger of failing, rather it typically reflects improved technology and/or a better understanding of, for example, earthquake or flood risks.

Third, once a water authority becomes aware of a deficiency in a dam it must take action to reduce the chance of a dam failure, or to reduce the consequences of such a failure.[30] Failure to take such action could be seen as a breach of duty of care to the affected community and, potentially, as negligence by the authority's directors should the dam fail.[31]

These observations made in the context of Victoria's commercialised water authorities appear to hold even more strongly in the case of Water Corporation, which is not only corporatised but operates under Corporations Law.[32]

Faced with the same level of risks, the same potential to reduce those risks and the same cost of doing so, it appears likely that directors of corporatised entities operating under Corporations Law, who may be personally, jointly and separately liable to be sued, will have a greater incentive to adopt a standards rather than a risk-based approach.[33]

Dam owners will be liable under common law if they fail to meet the standards even if the ALARP criteria indicate that it is unreasonable to do so. As a result, there are incentives for directors to minimise their liabilities by adhering strictly to the standards and ignoring what is merely reasonable to do. The State could choose to avoid the resulting additional expenditures by:

- using legislation or directions (say, under sections 6.4 of the Water Corporation Act) to instruct the Corporation to observe the ALARP criterion; and

30 Victoria's Infrastructure Planning Council (IPC) officers suggest that where there is a heightened chance of catastrophic failure, infrastructure owners will find it increasingly difficult to insure against that failure. They must either reduce the risk through remedial works or redesigning the facility, reducing operations to reduce commensurately the risk of failure, and, at its extreme, consider decommissioning. None of these options is costless. Each of the options will also raise funding issues.

31 This summary by the IPC did not reflect specific legal opinions obtained, nor any submission made. Rather it provides a summary of the general attitudes in the Victorian water sector, i.e., industry participants, government and regulators.

32 Prior to corporatisation of water authorities and other government business across Australia, governments effectively carried relevant risks and self-insured. The directors and management of water businesses must now consider more explicitly their responsibilities – and their potential personal liabilities – due to the combination of corporatisation:

- particularly the removal of the shield of the Crown and the discipline of Corporations Law; and
- the absence of specific legislation on risk levels and management.

This combination of factors creates a different dynamic between the corporatised government sector and the non-corporatised government sector when assessing and making judgements on risk management levels and behaviour.

Such differences may reinforce the previously observed differences in the amounts that government is paying to save a life in different areas of public sector activity.

33 Water Corporation advises that Board members have not been given any particular advice on their liabilities. When they join they are given a copy of the Act and the Corporations Law and if they are still interested they attend the Board meetings. They are advised on particular issues like dam safety when they arise.

- indemnifying directors for claims for losses attributable to the gap between ALARP and the limits of tolerability in cases where the limits of tolerability are unreasonable to achieve.

Fourth, most Australian states set ANCOLD guidelines and standards as their target and all then implement a program of dam safety upgrades – including operational changes and interim solutions – which moves to that target over time.

> *The management of the safety upgrades for our portfolio of dams is like being a sheepdog. The task is to keep the flock always moving toward the target (of the ANCOLD Guidelines/standards) and not let any one of them become a straggler.*[34]

Fifth, where there is a portfolio of dams and/or the problem/solutions are separable the most efficient risk reduction pathway is determined and followed. For instance, for SA Water,

> *… 25 separate risk reduction measures would be required to bring all 17 dams into line with current accepted practice of dam safety. The report ranked the projects to ensure that the program of rehabilitation projects would achieve the most cost-effective… risk reduction.*[35]

Sixth, the rate of proceeding down the pathway of efficient risk reduction must also be set and agreed consistent with the broader context of including capital constraints.

Thus, the view of Victoria's Infrastructure Planning Council (IPC) and individual dam owners is that the requirement to undertake immediate remedial investment is not absolute since there are obvious capital constraints.

The IPC notes that once a board becomes aware of any deficiency in its infrastructure it is required to do something. Such a decision must be consistent with the need to maintain the commercial viability of the entity and be cognisant of the additional liability that attracts to directors from failure to address.[36] Consequently, boards must address any potential failures within the context of their overall budgetary position. This may require prioritising works and reducing services until standards are met.

Goulburn-Murray Water provides a case study of this generic approach.[37]

> *As part of the first phase of a dam improvement program, Goulburn-Murray Water has reviewed the safety of its dams. To varying degrees, the dams do*

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34 *pers comm,* Melbourne Water, August 2002.

35 South Australian Water Corporation (2000) *Hope Valley Reservoir Rehabilitation Project*, Report to Public Works Committee, July, p. 2.

36 *pers comm,* Victorian IPC officers, December 2002.

37 Goulburn-Murray Water in its submission to the then Department of Natural Resources and the Environment in the Government's Expenditure Review Committee considerations.

not meet current safety standards, principally as a result of improved technical knowledge in relation to dam design and the magnitude of potential floods and earthquakes that has developed since the dams were constructed.

The estimated cost to upgrade all thirteen dams to current standards is $193.1 million, and $18 million of the $37 million made available through the current funding arrangement has been expended on urgent works and safety reviews.

In order to meet its obligations as a manager of large, high hazard dams, Goulburn-Murray Water has prepared a staged program of dam safety improvements, commensurate to the identified risks, over a fifteen-year period.

SA Water is also mindful of capital and financing constraints.

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. [38]

Similarly, Melbourne Water emphasised that despite the now small size of its remaining dam safety program that they were very mindful of other demands and priorities for capital when determining timing in particular.[39]

6.3 AS IF THEY OWNED THE ASSETS

In interpreting and understanding the Bulk Water Service Agreement, it is useful to understand the context and the interpretations provided by other closely related documents. The Cabinet Submission in 1996 is particularly relevant. This states:

The proposed bulk water price … is based on irrigation farmers paying on the same basis that they would pay if they owned the assets.[40]

This statement in the Cabinet submission clearly envisages that the bulk water price to irrigators would be established as if the irrigation farmers owned the dams rather than the Corporation. In terms of the SCARM/ARMCANZ pricing principles (Figure 7.1) below), the commercial viability guideline is being followed. We need to understand the implications of these differences.

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[38] Bowles, DS, Parsons, AM, Anderson, LR and TF Glover (1998) *Portfolio Risk Assessment of SA Water's Large Dams*, Proceedings of the 1998 Australian Committee on Large Dams (ANCOLD) Annual Meeting, Sydney, September.

[39] *pers comm*, Melbourne Water, December 2002.

[40] 1996 Cabinet Submission

First however, the key similarity must be stressed. As owner of the dams, Harvey Water would be bound by the same responsibilities as any owner of large, i.e., notifiable, dams. Thus, decisions on management and safety would be guided by ANCOLD as the only available standard in the absence of specific of Western Australian legislation. (Note that we could have – but have not – assumed that Harvey Water would have adopted the same stance as the four shareholder governments of River Murray Water and decided (consistent with the ALARP principle) that it was not worthwhile to move to the 10^{-6} risk standard for flood.)

However, Harvey Water is differently situated to Water Corporation. These differences include:

- the relevant magnitude of the proposed expenditures compared with the annual turnover of each entity;
- the limited funding and charging base from which to raise or levy additional funds;
- the limited capital expenditure budget within which to re-prioritise capital expenditures;
- the smaller corporate presence of Harvey Water compared with Water Corporation, and therefore the smaller target and likelihood for common law claims. Moreover, as noted by Goulburn-Murray Water, community expectations for public safety are higher for government agencies than for private companies so that Harvey Water and its directors can legitimately be expected to be less concerned over legal liabilities; and
- the very limited ability to secure additional funding from its shareholders. First because they are private individuals rather than government, and second because the shareholders are also Harvey Water's customers – they cannot afford to be hit twice.

As a result, Harvey Water as a dam owner would likely behave with a very acute awareness of its capital constraints and the opportunity costs of its available capital. This situation is not unique. It is clearly seen in the revealed behaviour of Goulburn-Murray Water, Melbourne Water and others and confirmed by our discussions with senior officers of the respective organisations.

Like Goulburn-Murray Water, Harvey Water could be expected to:

- endorse the movement to achieve ANCOLD Guidelines over a reasonable time period;
- use transparent and well-documented expert reviews and participatory workshops to validate a conservative but responsible approach to safety upgrade expenditures;
- thoroughly explore interim and staged solutions;
- act expeditiously to address *prima facie* and confirmed high risks;

- check carefully hazard and risk assessments to ensure that no expenditure is undertaken unnecessarily or ahead of or behind priority;
- undertake extensive consultation and workshopping with its customers to ensure that the agreed program of works and initiatives is fully accepted as are its financial consequences;
- apply special levies to raise funding before seeking debt funding to undertake the required remedial initiatives and works; and
- implement interim and staged solutions.

Thus, Harvey Water could be expected to act differently to Water Corporation in terms of its approach and the dynamics of implementing a responsible dam safety program. In particular, Harvey Water could be expected to give high priority to avoiding all unnecessary costs and delaying large expenditures within the limits of responsibility.

The difference in approach between Water Corporation owning the assets and Harvey Water owning the assets stems primarily from the differing degree of capital constraints on the two organisations. Within its capital expenditure program which is currently averaging around $400 million per annum, Water Corporation has been able to earmark special funds for dam safety of around $15 million per annum and as a result has planned to undertake the safety upgrades of all the South West Dams over an eight year period.

In contrast, dam owners such as Goulburn-Murray Water indicate clearly that they are more capital constrained and are staging their upgrade programs over periods of fifteen years and in some cases longer.[41] Staging a major dam safety program over a longer period than eight years is obviously judged to be reasonable by the boards of virtually all other dam owners in Australia.

The further question arises as to whether these differences are material. There are several reasons why such differences may be material.

> First, a longer timeframe may reduce the present value of the costs, but more importantly, could also reduce cash flow impacts on Harvey Water and individual irrigators.
>
> Second, a longer timeframe would make interim solutions more sensible. This can be seen by noting that the prime argument for undertaking all parts of the identified works program for Waroona at the same time was that it avoided

[41] We do not suggest that Water Corporation is free of capital constraints, but rather that they appear to apply much less severely than is the case for other water businesses. Water Corporation's capital program has been reprioritised due to the need to respond to the drought. In the past year, additional drought response projects worth $74m have been included in the Corporation's capital program, resulting in other projects being delayed. Part of the drought response has been to delay $16m of dam safety projects. Delays include Logue Brook remedial works by 1 year, the outlet refurbishment at Serpentine by 2 years and the new spillway at Samson Brook by 3 years.

emptying the dam twice and demolishing an interim structure, which would have been constructed only two years before. The decision to run the two phases together was based on the desire to avoid adverse public comment, particularly from the "community", i.e., the recreational users of the dam. On the then expected timing this combining of the two phases made little difference to the estimated total costs, although affecting the extent of risk reduction achieved in the short term.

Since the final stage of the Waroona upgrade was, on the basis of Water Corporation's own assessments, judged by the Portfolio Risk Assessment undertaken by David Bowles to be among the very lowest priorities, a longer phasing over, say, fifteen or so years would have made interim solutions relatively more attractive and sensible.

Third, the careful challenging of all risk assessments would undoubtedly have led to a finer set of judgements.

We note that the more detailed risk analyses undertaken by Drs Davidson and Nathan for this report suggest that Water Corporation's assessment may have been unduly conservative in several areas with the result that the benefits of the specific upgrades may be smaller than those used by Bowles with the result that the advantages of interim solutions may be significant.

As indicated in Chapter 4 above, more detailed and finer analysis of the various risks and modes suggests that piping risk and stability risk, and loss of life from flooding may, for example, not be anywhere near as severe as originally predicated on the basis of the preliminary risk assessments. Thus, the final SCUPs for Waroona would be further delayed and it is likely that there would have been greater reliance on interim solutions to reduce and manage risk.

Fourth, severe capital constraints force innovative solutions. This is already reflected in Harvey Water's approach to delivery infrastructure upgrades and refurbishment. Whereas the Corporation has approached the South West Dams as a segmented set of six dams, there is scope to view the issues of supply cost more globally. This is suggested by, for instance, the concentration of upgrade costs in the Waroona supply system and the very small volumes of deliveries from this system. Thus Harvey Water may have been willing to consider rationalisation of dams and supply (but this opportunity may now be reduced if not precluded).

It is beyond the scope of this review to establish precisely what differences would have arisen in dollar terms if the six dams were owned by Harvey Water, but our judgement is that such differences are likely to have been material. Moreover, there are also important lessons of principle.

In summary, consistent with the principle enunciated in the 1996 Cabinet submission that the prices for bulk water should be set as if the irrigators owned the assets, we consider that the efficient cost of the dam safety upgrades should be defined in the same way, and the resulting differences, although unquantifiable, are likely to have been material, at least for Waroona and possibly for the supply system as a whole.

We consider that ANCOLD standards would have provided the same light on the hill, but there would have been a finer and different assessment of risk, much higher levels of stakeholder understanding and acceptance of the financial consequences, some different solutions including greater use of interim and management solutions with the completion of the final program pushed out over a longer period.

These differences between a dam safety program developed and implemented by the Corporation compared with a program developed by Harvey Water, reinforce the need for best practice approaches to be adopted for the remaining five dams.

We now turn to the funding of these costs.

7 COST-SHARING & PRICING PRINCIPLES & PRACTICE

The purpose of this Chapter is to set out the principles, practices and issues relevant to the sharing of costs for Dam Safety Upgrades (DSU) in the South West and elsewhere. We therefore review:

- the general principles and note that multiple conditioning factors apply in practice;
- the practical outcomes for cost sharing in other Australian jurisdictions;
- the beneficiaries of the dams, the water and the safety upgrades;
- legacy costs. Because these issues have been most thoroughly and comprehensively reviewed by IPART, we pay particular attention to IPART's framework and views on the relevance of legacy costs, and the question of whether this framework can be directly applied to the South West Dams;
- the Bulk Water Service Agreement;
- the question of price impacts and affordability as indicated by Department of Agriculture surveys of farm performance, water use and profitability amongst South West irrigators; and
- the pricing impact of treating safety upgrades as if Harvey Water owned the assets itself.

7.1 PRINCIPLES

Two major principles begin any debate on the allocation of cost. These are the impactor pays principle, sometimes termed the polluter pays principle, and the beneficiaries pay principle. Descriptions of these two principles can be found in most reviews, e.g., IPART (2001) review of Bulk Water Pricing or the recent PARIC (2002) review on water pricing for the NCC. Our brief description below is based on IPART.

- 'Impactor pays' and 'beneficiary pays' are both approaches for addressing the problem of how to allocate costs that arise within a system – such as the NSW bulk water system. These costs could arise directly, in order to deliver particular services. They could also arise indirectly, through investments designed to reduce the damage resulting from the service delivery.
- Impactor is defined as any individual or group of individuals whose activities generate the costs or a justifiable need to incur the costs that are to be allocated. The impactor pays principle seeks to allocate costs to different individuals or groups in proportion to the contribution that each individual or group makes to creating the costs or the need to incur the costs. [The impactor pays principle is a generalised version of the polluter pays principle.]
- Beneficiary is defined as any individual or group of individuals who derive benefits from the costs that are to be allocated. These benefits may result from their own use

of the services involved (in which case the beneficiary is also the impactor) or be in the form of reduced damage to their interests due to the usage patterns of others. In the latter case the beneficiary is sometimes referred to as the victim. The beneficiary pays principle seeks to allocate costs to different individuals or groups in proportion to the benefits that each individual or group stands to derive from the costs being incurred.

- Note that the allocation principles do not require that the costs be met solely by the direct impactor or beneficiary unless these are final consumers. The costs may well be passed on to end users in the form of higher prices for goods or services derived from the use of the resource system

These two principles provide clear extreme rules for cost allocation. Note that they are essentially accounting rules since they take no account of response and elasticities and therefore may not be efficient.

A recent and relevant example of the impactor pays principle is IPART's consideration of bulk water pricing for NSW. IPART allocated costs between extractive users and the broader community, represented by the Government, essentially in proportion to the contribution each group makes to creating the costs or the need to incur the costs. In so doing IPART considered that the impactors causing the need for expenditure variously include both:

- the community, in changing the standards which natural and built infrastructure is required to meet and in requiring increased levels of environmental resource and asset management; and
- bulk water users, by creating the need for system management expenditure, environmental mitigation and, effectively, by requiring ongoing bulk water delivery from assets which might otherwise be decommissioned rather than upgraded to meet contemporary standards.

We note that these definitions are essentially a description of IPART's conclusions *inter alia* on affordability. They are not a direct outcome of the impactor pays principle as such. This is demonstrated by noting that community standards applied by the EPA to a chemical plant or a notifiable site are treated as a cost of doing business for the operation, whereas an increase in community standards affecting irrigators is treated as a benefit to the community, rather than a cost of doing business.

The two allocation accounting rules therefore need to be supplemented by economic criteria, namely:

- demand efficiency;
- supply efficiency; and
- equity.

Other criteria and factors are also likely to be relevant. For instance, Goulburn-Murray Water in a recent submission on its dam safety program listed the following aspects as relevant to cost sharing:

- an inherited backlog of dam safety obligations;
- the hazard presented by a large dam is a function of the extent of downstream development that is not within the control of Goulburn-Murray Water;
- community expectations for public safety are higher for Government agencies;
- the broader public safety, welfare and state and regional economic benefits reliant on dam safety. Some examples are tourism, irrigation-dependent industries, flood mitigation and recreation;
- significant community costs would be subsidised by irrigation customers should they be asked to meet the total dam safety cost;
- State Government ownership of Goulburn-Murray Water's business; and
- the bulk water price on the Goulburn System would nearly double should customers be required to fully fund the necessary dam safety upgrading.

Without endorsing each and every one of these factors, it is clear that decisions on cost sharing go beyond a simple consideration of beneficiaries vs impactor pays.

A key issue in any cost-sharing arrangement are the issues of response and affordability. Efficient cost sharing is an economic issue and there is no point in applying accounting rules which impose cost burdens which force that group of customers out of the system. This is a matter of both equity and, importantly, of efficiency and underpins the economist's concept of efficient cost discrimination.

7.2 DAM SAFETY COST ALLOCATIONS IN OTHER STATES

7.2.1 MDBC DAMS

The bulk of Australia's irrigation and irrigation dams are located in the Murray Darling Basin and several of Australia's major dams are controlled by the Murray Darling Basin Commission (MDBC). These include, Hume and Dartmouth Dams, Yarrawonga Weir and the weirs/locks along the River Murray.

The MDBC has, through River Murray Water, spent considerable amounts to upgrade the safety of its dams over the past decade, particularly on Hume Dam and Yarrawonga Weir.

River Murray Water advises that in the case of Hume Dam, it will now withstand a flood of 10^{-5} and that the four shareholder governments are aware that an additional \$100 million or so that would be required to move to a 10^{-6} flood standard.

As a result, River Murray Water is continuing to examine the flood hydrology to refine further those estimates and develop costed options which the governments can then evaluate against other large demands for capital.

River Murray Water emphasises the need to engage communities in understanding and influencing decisions to be taken and the need for emergency awareness and action programs to be developed in conjunction. This is particularly relevant since lesser floods in the 10^{-2} to 10^{-3} range can substantially impact communities such as Albury-Wodonga.

Under the Agreement between Commonwealth, NSW, Victoria and South Australia, the Commonwealth is responsible for 25% of all capital costs, including safety upgrades.

The impact of this agreement is therefore that the states collectively are responsible for only 75% of capital costs. As a result, even if all states were to allocate all their share of the costs directly to irrigators, all irrigators would, over the long term, pay no more than 75% of the total capital costs.

If all relevant states followed NSW policy and Victoria practice and attribute 50% of their costs to irrigators, then irrigators would meet only 37.5% of total capital costs.

Because the capital costs of River Murray Water are treated as common costs to be shared between the relevant states, there is a dichotomy between being a beneficiary of a specific piece of infrastructure and paying for that benefit. For individual projects, a state may benefit 100% from an upgrade or replacement of a structure, but may only pay its agreed share of the costs. An example of this in the mid-1990s is Torrumbarry Weir which serves primarily Victorian irrigators. With the collapse of the Weir, the Commonwealth and all three states contributed to its reconstruction so that Victoria paid its share only which at the time was 25%.

Initially, each state was responsible for one-third of the 75% allocation of capital costs attributable to the three states. Since 1998, in line with the recommendations of Marsden Jacob (1995), River Murray Water has reassessed how the 75% of costs allocated to the three states collectively should be apportioned. Rather than the previous one-third each, the shares for NSW, Victoria and SA, based on current levels of service which are regularly reviewed, are now 40%, 36% and 24%, respectively. Alternatively expressed, the three states are responsible for 30%, 27% and 18% respectively of total capital costs with the Commonwealth continuing to pick up the remaining 25%.

State practices on cost sharing for MDBC dams are set out below.

NSW

NSW irrigators are charged 50% of capital costs to the State for MDBC dams and associated safety upgrades. Thus under the current state allocation, NSW irrigators pay at most 15% (i.e., 50% times 30%) for safety upgrades on MDBC dams and other capital expenditure by River Murray Water. However, other factors intervene and it appears that NSW irrigators have paid less than 15% for recent safety upgrades in MDBC dams.

Victoria

Victorian irrigators do not have the certainty of a fixed policy on cost sharing with the State Government and all major funding initiatives must be negotiated. In the case noted above of Torrumbarry Weir in the mid-1990s, Marsden Jacob Associates undertook a detailed evaluation of the beneficiaries for the Victorian Government and concluded that the irrigators accounted for around 55% of the benefits with the balance accruing primarily to tourism, recreation and the towns.

The Government's decision was to share the costs with irrigators on a 50 : 50 basis with the result that Torrumbarry irrigators paid 12.5% (50% times 25% – the Victorian allocation at that time).

Under current state allocations for River Murray Water, Victorian irrigators are expected to pay 13.5% (i.e., 50% of 27%) of the total capital costs including safety upgrades.

South Australia

South Australian governments have been highly protective of their irrigators and the cost of the MDBC upgrades has been paid fully by Adelaide customers rather than the irrigators.

Queensland

Queensland is part of the Murray-Darling system of rivers but benefits from none of the MDBC state-owned dams.

Summary

As set out above, in total irrigators in the Murray Darling Basin currently pay no more than 28.5% of the capital costs of the safety upgrades across all MDBC dams. This maximum is set by:

- the Commonwealth paying 25% of the capital costs including safety upgrades;
- the determination by IPART that NSW irrigators pay 50% of effective capital costs (as distinct from capital costs actually incurred);
- the practice in Victoria that irrigators pay 50% of relevant capital costs (which excludes some MDBC assets); and
- the current policy of the South Australian Government that irrigators pay no part of the capital costs incurred in the regulation of assets in the Murray Darling Basin.

The current South Australian policy does not appear to comply with the South Australian government's responsibilities as a signatory to the National Competition Agreements. If South Australia were to move to the same (50%) policy as NSW and Victoria, then the share of costs of safety upgrades would rise to a maximum of 37.5%. Table 7.1 outlines this situation.

Table 7.1 : Allocation of Costs of Dam Safety to Irrigators – MDBC Dams

Proportion of Capital Costs Recovered from User			
	Contribution to state allocation	**Contribution to total allocation**	**Irrigator share**
NSW	50%	≤15%	
Vic	50%	13.5%	
SA	–	–	
Qld	n.a.	n.a.	
All irrigators	varies	≤ 28.5%	≤ 28.5%
Consistent policy*			37.5%

* If all irrigators payed 50% of their state's allocation.

7.2.2 State-owned Dams

For NSW, Victoria and SA, the same cost sharing practices apply to state-owned dams as they do for allocation of the state's share of MDBC dams. As noted above, in broad terms this is currently 50%, 50% and zero allocated to irrigators for the three states, respectively .

In Victoria, for the first phase of the dam improvement program, $37 million was established on the basis of equal funding from the State Government and Goulburn-Murray Water customers. Goulburn-Murray Water is now seeking a similar equal contribution for the $193 million program for dam safety upgrades.

Queensland's dams are operated by local government for domestic and residential supplies and by SunWater for irrigation. The policy of successive Queensland governments has been to provide a major capital subsidy for infrastructure expenditures incurred by local governments. Currently, this subsidy is set at 40%.

As a corporatised entity outside the local government sector, SunWater is not covered by this policy but the 40% subsidy sets a benchmark in SunWater's negotiations with the State treasury. SunWater's pricing for the Burdekin has recently been reviewed by the Queensland Competition Authority which concluded that SunWater's pricing would need to reflect the very diminished ability of the Burdekin irrigators to afford increases. Thus, 60% would appear to represent the maximum that irrigators are likely to be asked to pay for dam safety upgrades in Queensland, with the Burdekin outcome suggesting that they would be asked to pay little or no part of dam safety upgrades in some cases. These observations are summarised in Table 7.2 below.

Table 7.2 : Allocation of Costs of Dam Safety to Irrigators – State-owned Dams

Proportion of Capital Costs Recovered from User			
	Contribution to state allocation	**Contribution to total allocation**	**Irrigator share**
State-owned dams			
NSW	50%		50%
Vic	50%		50%
SA	–		–
Qld	≤ 60%		≤ 60%

* If all irrigators payed 50% of their state's allocation.

7.3 IDENTIFICATION OF BENEFICIARIES

Beneficiaries need to be identified according to whether they are beneficiaries of:

- the water that is made available;
- the dams themselves, i.e., their harvest and recreational tourism capacities; and
- the dam safety upgrades.

As noted in Chapter 4, information available to assess beneficiaries of dam safety is inadequate. The risk assessment undertaken in the development of the safety program focussed on societal risk with little or no consideration of loss of individual lives nor the impacts on the economic activity in the immediate vicinity or through Bunbury. As a result, qualitative statements only can be made and magnitudes can only be indicated.

Irrigation customers of Harvey Water benefit from dam safety in that it reduces the risk and costs associated with:

- inundation following a dam break; and
- the loss of production that would be forgone due to the absence of water available for irrigation in the period post the dam break to construction of a new dam.

However, irrigators are not the only beneficiary of improved dam safety.

Other extractive users similarly benefit to the extent that it reduces the risk of supply not being available due to dam failure or a requirement to reduce the level of service/supply in order to reduce the risk of dam failure. This is the case with a number of the South West Dams where industry and Water Corporation itself have licences to extract water. Examples include Samson Brook, Stirling and Wellington Dams. In such cases, any dam safety costs allocated to extractive users need to be commensurate.

Recreation and tourism are also important beneficiaries of dam safety improvements, particularly where active use is made of the dam such as boating and water skiing. Such active use is important on a number of the South West Dams including Waroona, Drakesbrook, Logue Brook and up until recently, Samson Brook.

The importance of recreation and tourism as beneficiaries of dams is reflected by the fact that these groups – rather than the irrigators – were actively consulted by Water Corporation in its decision to undertake the suite of dam safety upgrades for the Waroona Dam. These users and the local community, represented by local government, preferred the works to be undertaken in a single stage rather than over multiple stages as it reduced the frequency and period over which the dam would not be able to be utilised.

By comparison, Harvey Water, the main licence holder to the water in the Waroona Dam, was not consulted by Water Corporation. This helps illustrate the importance these other non-extractive users of dams are as beneficiaries of dam safety improvements.

Another example of the relative importance of recreation and tourism activities associated with dams in the Waroona catchment is the recently prepared Draft Waroona Waterways Recreation and Tourism Master Plan.[42] The draft Master Plan sets out a blueprint for future recreation and tourism use of the catchments in the Waroona area. Again, the importance of these activities is highlighted by the fact that Harvey Water, the major user, was not consulted during the development of the draft Master Plan.

The owners of infrastructure assets downstream of dams also benefit from improved dam safety as it reduces the risk and costs of damage or destruction caused through dam failure. Moreover, improved dam safety reduces consequential costs such as asset rectification, loss of business, loss of lives that may occur as a result of dam failure. Such beneficiaries arise in the case of all the South West Dams with important examples including the various townships downstream of the dams, the South West Highway, Telstra’s optic fibre cable, the railway and so on.

Arguably, the directors of Water Corporation are beneficiaries of dam safety improvements in that it reduces the risk of them being held liable should a dam fail. As noted, directors of corporatised entities such as Water Corporation have a strong incentive to minimise such liability even though the costs associated with reducing the risk of dam failure, hence improvement in public safety, is disproportionate to the costs of improving public safety elsewhere in society, e.g., improved rail crossings, enforced use of seat belts in buses and so on.

[42] Regeneration Technology, 2002. Waroona Waterways Recreation and Tourism Master Plan prepared for Water Corporation in conjunction with Shire of Waroona, Department of Conservation and Local Management and Water and Rivers Commission, November.

Table 7.3 : Comparative Water Use & Recreation Use in South West Dams

Dam	Yield GL	Harvey Water Allocation GL	Recreation Permitted
Waroona System			
Waroona	7.9	7.9	Yes
Drakesbrook	1.8	1.8	Yes
Samson Brook	8.3	7.8	Until recently
Total	**18.0**	**17.5**	
Harvey System			
Stirling/Harvey	83.0	57.0	No / Yes
Logue Brook	11.0	11.0	Yes
Total	**94.0**	**68.0**	
Collie System			
Wellington	100.0	68.0	No*
Total South West	**212.0**	**153.5**	

* Collie Shire and the community hold strong positive views on the recreational value of Wellington Dam.

7.4 LEGACY COSTS

The key step in IPART's 2001 price setting process for bulk water was to determine what portion of the total efficient cost base should be allocated to the users of bulk water (and therefore recovered in bulk water charges) and what portion should be allocated to the government (and therefore borne by the community). As noted by IPART, this issue arises because:

- the costs incurred by DLWC in managing the rivers, dams, weirs and other parts of the NSW bulk water system are not related exclusively to bulk water delivery. For example, some of these costs are incurred to meet other needs, such as environmental protection, flood mitigation and navigation; and
- some current and future costs relate to past practices and activities. The inclusion of these 'legacy' costs in today's prices may distort the signal to users of the current and future cost of providing bulk water services.[43]

On the other hand, IPART was sympathetic to the view that:

> *… it is unreasonable for users to pay nothing towards the costs of upgrades to meet future occupational health and safety standards and environmental impact mitigation costs.* [44]

Having considered the issues, IPART concluded that it was appropriate to draw a "line in the sand" at a particular date and to consider only expenditure required to meet

[43] IPART (2001) *Department of Land & Water Conservation, Bulk Water Prices,* October, p. 27

[44] IPART (2001) p. 31

standards established at or before that date as forming part of the legacy. Consistent with its views on valuing physical assets, the Tribunal decided to draw the line in the sand at July 1997. Expenditure required to meet standards established after that time did not therefore form part of the legacy.[45]

Therefore the Tribunal classified as legacy costs those current and future costs attributable to past (pre 1997) activities and/or the cost of restoring natural and artificial infrastructure to prevailing 1997 community standards.

Compliance costs

IPART noted that the areas which generated the highest level of stakeholder concern over cost allocations were compliance capital costs. These include capital costs associated with ensuring structures such as dams and weirs comply with relevant dam safety standards, meet relevant public safety and occupational health and safety standards and comply with contemporary standards to mitigate the environmental impacts of stream interruption.[46]

IPART similarly reviewed the allocation of compliance capital costs in the areas of occupational health and safety and public safety and concluded that these represent a mix of legacy and non-legacy costs which are attributable to both extractive users and the community.[47]

The resulting cost allocations are summarised in Table 7.4. Of particular relevance in the conclusion that the capital costs of compliance which required dam safety upgrades should be split 50/50 between irrigators and the NSW government.

Where these safety upgrades relate to MDBC dams, then the Commonwealth meets 25% of the costs leaving a maximum of 37.5% of costs to be met by the irrigators.

[45] IPART (2001) Department of Land & Water conservation, Bulk Water Prices, October, p.31

[46] IPART (2001) Department of Land & Water Conservation, Bulk Water Prices, October, p. 33

[47] IPART (2001) Department of Land & Water Conservation, Bulk Water Prices, October, p. 34

Table 7.4 : IPART Cost Allocations

Sub Product Code	Sub Product Long Name	Revised Allocation User	- Government	Comment
PC330	Dam Compliance Environment	50%	50%	A significant legacy component, but need for expenditure arises from continuing presence of sstructures. Removal would be an alternative option in some cases but for ongoing extraction requirement. Tribunal therefore considers equal share appropriate and consistent with the impactor pays principle.
PC331	Dam Compliance, OHS and Public Safety	50%	50%	OHS costs are borne by businesses generally rather than Government. Includes some public safety costs not necessarily attributable to extractive users and some legacy component, Tribunal considers it appropriate to pass through to users a significant share.
PC332	Regulated River Compliance Environment	50%	50%	As with other environmental compliance sub-products, the Tribunal considers an equal sharing appropriate.
PC333	Regulated River Compliance, OHS and Public Safety	50%	50%	As with other OHS and public safety costs, the Tribunal considers an equal sharing appropriate.
PC334	Unregulated River Compliance, OHS and Public Safety	50%	50%	As with other OHS and public safety costs, the Tribunal considers an equal sharing appropriate.
PC335	Unregulated River Compliance, Environment	50%	50%	As with other environmental compliance sub-products, the Tribunal considers an equal sharing appropriate.

Source: IPART (2001) *Department of Land & Water Conservation, Bulk Water Prices*, October, p.35

The approach to legacy costs adopted by IPART follows directly from the adoption of "*a line in the sand*" set at 1 July 1997. This is explicit in IPART's description of its approach.

As noted by IPART,

> *the legacy principle is linked to the Tribunal's prior decision to adopt a "line in the sand" approach to the valuation of infrastructure assets in the bulk water system.*

In seeking to regulate bulk water prices, IPART had been presented with a mess and tangle of pre-existing subsidies, uneconomic investment decisions, and implicit agreements and understandings. Thus, IPART needed a simplified method or convention to cut through and to proceed. In the absence of other, specific agreements being in place, IPART adopted the simple and clear convention of "a line in the sand" whereby regulatory asset values as at 1 July 1997 are set to zero and all costs that should have been incurred up to that date, but have been deferred, are treated as legacy costs, i.e., costs which should not be reflected in current prices.

On this basis, the costs of safety upgrades for NSW dams were treated as "legacy" costs to be paid by the State Government rather than be imposed on the current generation of irrigators. [48]

This logic is internally consistent. The issue is, does it have direct relevance and application to the South West Dams ?

For it to do so, there must be a need for "*a line in the sand*".

This is a critical point. As confirmed with senior IPART officers, had explicit decisions been taken by DLWC, the Government or others to establish new agreements, protocols or contracts to end the historical tangle of subsidies and muddled accountabilities then these would have precluded IPART from establishing its convention of a line in the sand based on 1 July 1997.

In the NSW case there were no such agreements relevant to the pricing of bulk water. However, such agreements/contracts are in place in Western Australia. Specifically, there is a Bulk Water Service Agreement in place between SWIMCO and the Corporation.

Importantly, the BWSA acknowledges that there is a need for safety upgrades and that the costs will be borne at least in part by the irrigators through Harvey Water.

Whereas in the privatisation of Western Australian irrigation schemes, the scheme assets have been handed over as fit for purpose (or have had monies paid for backlog maintenance), the BWSA explicitly acknowledges that the bulk water assets, i.e., the dams, required upgrading and that the irrigators would be required to fund at least part of this cost.

Thus, we conclude – unless it can be concluded that the relevant clauses of the BWSA should be set aside – that the line in the sand convention and its corollary, legacy costs, does not <u>directly</u> apply to the case of the safety upgrades for the South West Dams.

Nonetheless, we observe that the comparison of the potential outcomes remains relevant. The NSW circumstances and approach results in irrigators paying only 37.5% or 50% for the safety upgrades of MDBC and NSW dams respectively, while, in contrast, south west irrigators are contracted to pay potentially up to 100% of costs incurred for safety upgrades.

[48] *pers comm*, Colin Read, IPART, December 2002.

7.5 THE BULK WATER SERVICE AGREEMENT

The Bulk Water Service Agreement (BWSA) was negotiated in 1996 as part of the separation and privatisation of South West Irrigation. The key sections have been outlined in Chapter 1 of this report, but it is useful to repeat them here and to provide our interpretation and comment on them.

The key elements of Section 5.4 are:

(a) The Bulk Water Price may be increased during the Term or the extended period as a consequence of any increased cost to the Corporation brought about as a result of any Safety Upgrades required to the South West Dams.

This foreshadows the likelihood of dam safety upgrades and the expectations that irrigators will be called upon to share part, or all of the upgrade costs. It does not imply that irrigators must necessarily pay 100% of the costs incurred.

(b) The parties expressly agree that there is to be no increase in the Bulk Water Price attributable to the costs incurred by the Corporation in constructing and operating the proposed Harvey Dam or carrying out Safety Upgrades to Harvey Weir.

Harvey Weir and Harvey Dam are specifically excluded from a) above.

(c) The parties agree to negotiate in good faith any Bulk Water Price increase referred to in subclause (a), but failing agreement within 3 months of negotiations commencing between the parties, the revised price will be determined by the Minister for Water Resources after consultation with the Coordinator of Water Services and the parties.

This provision creates a mechanism for resolving differences.

(d) The parties acknowledge that in any negotiations under subclause (c), a relevant issue governing any increase in the Bulk Water Price or the magnitude of that increase, will be the extent to which any parties other than Swimco and the Corporation have benefited or will benefit from the relevant Safety Upgrade.

This explicitly acknowledges the presence of other beneficiaries and the expectation that the magnitude of any price increases to irrigators will be reduced accordingly.

(e) The parties further acknowledge that the negotiations contemplated by this subclause may take place at the time the Corporation is committing to the Safety Upgrade and before the date on which the relevant Safety Upgrade is completed, it being agreed that any

> *increase in the Bulk Water Price will not take effect until after the upgrade is completed.*[49]

This confirms that irrigators will not face increased prices until the relevant upgrade is completed. Implicitly, this means that prices would be increased following each separate upgrade.

As noted, the BWSA defines Safety Upgrades as any work:

a) *which, in the reasonable opinion of the Water Corporation, is required in order to maintain the safety of the South West Dams in accordance with the publication entitled "Guidelines on Dam Safety Management 1994" published by the Australian National Committee on Large Dams (ANCOLD) (as the same may be amended from time to time) or as required by any relevant law or regulation; or*

b) *required by any governmental agency in relation to the safety of South West Dams.*

These definitions are interpreted as referring to the corpus of Guidelines developed by ANCOLD covering the risks and management of large dams including piping, flood and seismic risks. The second element of the definition makes it clear that requirements for upgrades for the purposes of occupational health and safety are also included.

Comment

At the time of negotiating the BSWA, the need for safety upgrades was acknowledged explicitly by all parties and the indicated costs were around $17-20 million. While the cost estimates were neither precise nor capped, any expectation that costs might prove to be a multiple of the indicated levels would likely have led to a breakdown in the privatisation negotiations, a delay or the request to cap or otherwise fix or share the liability to Harvey Water.

The most recent estimates of the cost of the dam safety program are $102 million, or five to six times the levels indicated during the privatisation negotiations in 1996.

We understand that Water Corporation officers from both head office and the region met with the South West Irrigation in December 2001 to first inform them that the expected costs of the safety upgrades had risen to around a nine figure level.

Quite separate from the question whether irrigators can afford to pay the eighteen-fold rise in bulk water prices (see Section 7.7 below), a question arises whether the irrigators should be held to be liable for a six-fold rise in the originally indicated costs.[50]

[49] Water Corporation and South West Irrigation Management Co-operative Limited, Bulk Water Supply Agreement (1996), p.11.

As the monopoly supplier of water to the South West irrigators, the responsible agency for the safety of dams in Western Australia, and the centre of dam safety expertise in the State, we consider that the Water Corporation has some obligation that it should be able to be relied upon by smaller counterparties in contract and pricing negotiations.

On the other hand, it appears to be precisely the high degree of uncertainty that led to Section 5.4 of the BWSA being drafted to give a wide degree of discretion.

In summary, we conclude that the BWSA creates the expectation that irrigators will need to pay some part of the costs of safety upgrades of the South West Dams, but the Agreement is not prescriptive leaving considerable discretion for consideration of other factors in the negotiation and decision process.

We also conclude that, for a variety of reasons, the increase in projected costs by a multiple (currently around six fold) suggests that this discretion needs to be used.

7.6 AFFORDABILITY

7.6.1 IMPACT ON PRICE OF WATER

As noted, the cost of the proposed dam safety upgrade program is estimated at around $102.5 million spread over an 8 year period. Spreading this cost over an 80 year period at an interest rate of 6% translates this capital sum into an estimated annual cost at the completion of the program of around $31.87 per ML of nominal yield. The price increase to irrigators would be substantially higher than this, however, due to the fact that Harvey Water does not currently receive its full nominal allocation and losses through the distribution system mean that actual farm deliveries of water are less than the bulk water drawn in any given year.

Using the estimated costs and timing of the South West Dam upgrade program provided by Water Corporation, an analysis was undertaken to estimate the cost to irrigators by system of the program (Table 7.5).

[50] We note there appears to be some parallels between this case and the blowout in the estimated costs of foreign currency loans provided by Westpac Banking Corporation to farmers in the late 1980s.

Table 7.5 : Farm Gate Cost of Dam Safety Upgrade Program

System	Annuity	Irrigation as % Total Yield	Adjusted Annuity	Bulk Water	Deliveries	Bulk Water cost	Delivered Cost
	$000s	%	$000s	ML	ML	$/ML	$/ML
Waroona	2,416	84	2,029.96	9,787	7,409	207.42	273.98
Harvey	1,529	73	1,111.34	51,539	41,296	21.56	26.91
Collie	2,255	68	1,540.95	50,414	33,212	30.57	46.40
Total	**6,211**	**72**	**4,682.26**	**111,740**	**81,917**	**41.90**	**57.16**

The main points to be drawn from the analysis include:

- the cost per ML of dam safety differs substantially between the three systems, with the farm-gate cost for Waroona estimated at around $274 per ML compared with around $27 per ML for the Harvey system. The cost for the Collie system, estimated to be $46 per ML, lies between the two other systems;
- if the current practice of Harvey Water to equalise prices across all three systems were retained, the equalised cost is estimated to be $57.16 per ML delivered or $43.17 per ML of entitlement.

The average system cost of $57 per ML represents a seventeen-fold increase in the effective farm-gate cost of bulk water. Moreover, it would represent around a 120% increase in the total delivered cost of water.

7.6.2 IMPACT ON FARM PROFITABILITY

Such an increase in the cost of water would have a significant impact on the profitability of irrigated enterprises, particularly those based on irrigated pasture such as dairying and beef.

In order to gain insights as to the nature and magnitude of such impacts, use was made of the Department of Agriculture’s Dairy Farm Performance (DFP) survey data. The analysis examined the impact of dairy prices and the cost of water on farm operating profits. It should be noted that:

- the survey was based on only a limited sample of ID farms for the 2000/01 and 2001/02 period; and
- the farms participating in the DFP survey *“…tend to be the better farms, with higher operating profits.”* That is, the results tend to be biased towards the better farms.

Nonetheless, the analyses provided useful insights as to the relative impact of managing levels of recovery of the cost of dam safety upgrades on the dairy industry within the South West Irrigation Area. The analyses examined the impact on farm operating profit of:

- 25%, 50% and 100% recovery of the $57.16 per ML estimated cost of the dam safety program; and
- average milk prices of $0.30, $0.25 and $0.20 per litre.

Such impacts were examined in terms of the average of all survey farms and the average of the top four farms and the bottom four farms in terms of operating profit per dairy area. The results are illustrated in Chart 7.1 below.

The main findings from the analyses of price impacts and affordability include:

- a seventeen fold increase in the bulk water price and 120% increase in the total delivered price of water if irrigators are required to fund 100% of the currently projected relevant total cost of the dam safety upgrade program in the South-West ;
- farm operating profit is very sensitive to changes in milk prices. For the survey period, the price received for milk averaged just below 30 cents per L. Given that average prices have reduced substantially due to deregulation of the Australian dairy industry, dairy farmers within the South West have already incurred substantial reductions in farm operating profits.

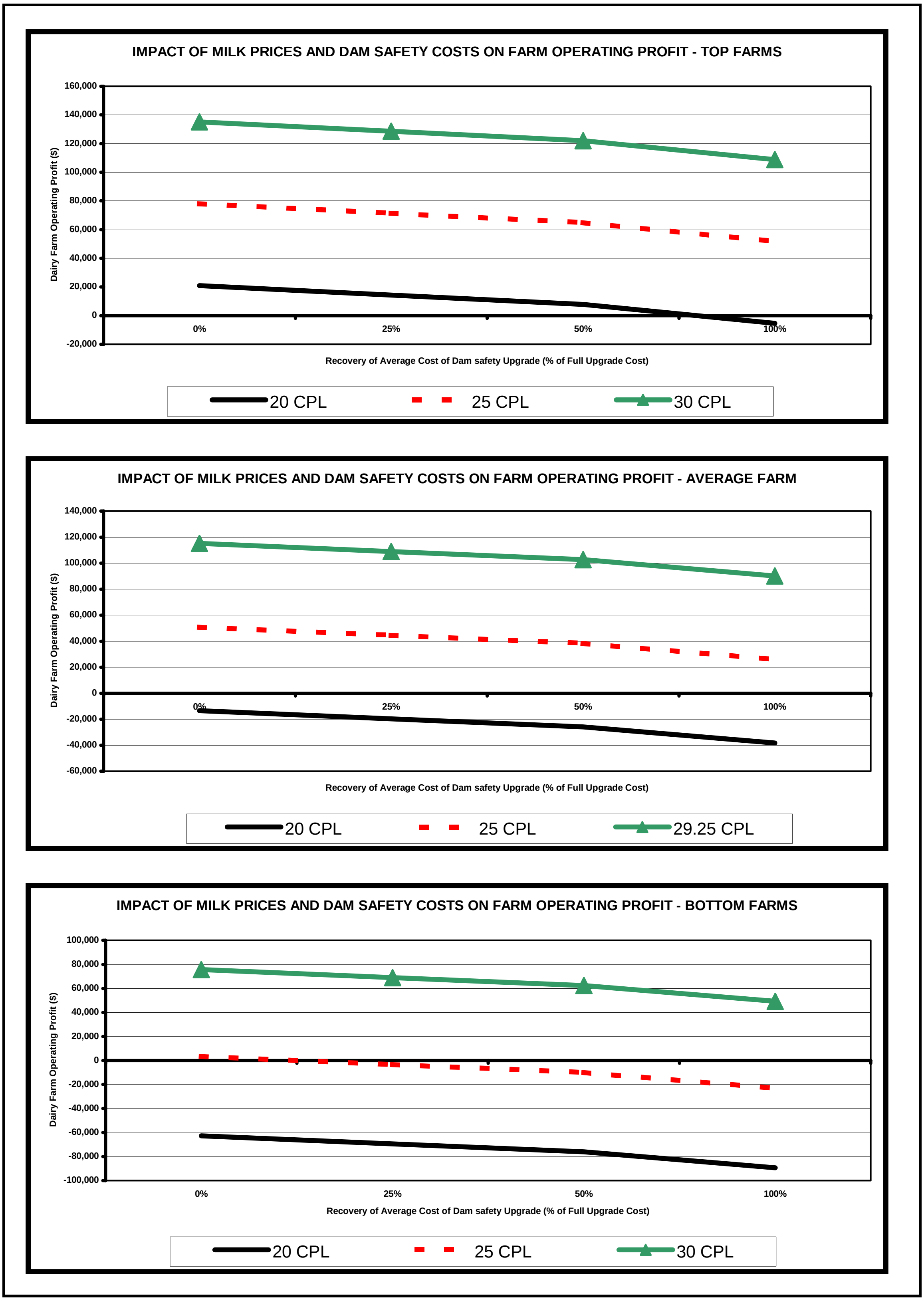
  A $0.05 per L reduction in milk price from $0.30 to $0.25 per L results in more than a 50% reduction in farm operating profit for the average survey farm, i.e., from around $115,000 to $51,000, with similar percentage reductions experienced by the top and bottom farms;
- full recovery of the cost of the dam safety program, i.e., $57 per ML delivered would result in a reduction in farm operating profit of $30,000 per farm for farms considered by the Department to be better than average; and
- the combination of reduced milk prices and increased cost of water places all dairy farms under significant financial pressure.

Whilst we had no access to any farm survey information for horticulture, it is likely that the impact of increased water prices on horticultural farms will be less acute than for dairy farms. This is because they are likely to use less water than dairy farms and the cost of water represents a smaller proportion of the overall cost structure compared with irrigated dairy farms.

This suggests that the impact of large rises in the bulk water price will be to push the balance of irrigated activity out of dairying into horticulture – other things equal.

In comparative terms, these cost and price impacts are dramatically greater than those encountered in the eastern states. This is due in large part to the very small size of the South West Dams in terms of their yields and the fact that dam safety upgrades are expensive no matter what the size of the dam or its yield.

Chart 7. 1 : Impact Of Milk Prices & Dam Safety Costs on Farm Operating Profit

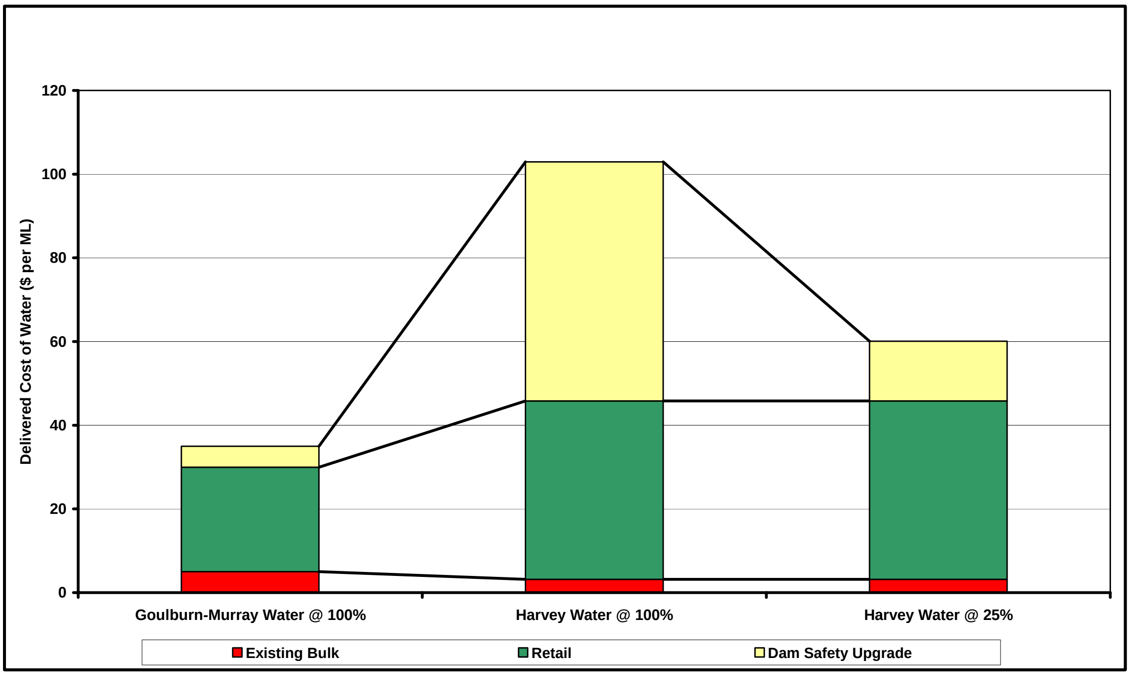


Cost sharing arrangements in the eastern states have been set for relatively small increases in costs per ML of water diverted, i.e., where concerns over price impacts and affordability although real are small, when compared with the South West situation.

Thus, one of the reasons for Goulburn-Murray Water proposing a 50/50 sharing of dam safety upgrade program costs is that if a 100% contribution by irrigators were required it would lead to a doubling of the bulk water price.

By comparison, a 100% contribution by South West irrigators would lead to a 17 times increase in the bulk water price and a 120% increase in the final cost of water to irrigators (refer Chart 7.2).

Chart 7.2 : Comparison of Impacts of Dam Safety Upgrade Costs on Water Prices



7.7 PRICING & ANNUITIES UNDER THE "AS IF THEY OWNED IT" CONVENTION

As previously noted, the Cabinet Submission in 1996 states:

> *The proposed bulk water price … is based on irrigation farmers paying on the same basis that they would pay if they owned the assets.*[51]

In Chapter 6 we explored the implications of this convention for the determination of acceptable risk levels and the priority and timing of dam safety programs. We also noted that the statement in the Cabinet Submission clearly envisaged that the bulk water price would be established as if the irrigation farmers owned the dams rather than the Corporation. Here too, we need to understand the implications of these differences.

For the purposes of calculating the CSO payable by Treasury, Water Corporation estimates the maximum revenue level that it would be permitted as a regulated monopoly, and then subtracts actual revenues received. To calculate the maximum

[51] 1996 Cabinet Submission

revenue level, Water Corporation applies a 6% return. This rate of return is the deemed maximum that the Corporation is allowed to charge as a monopolist.

In contrast, Harvey Water's customers are also its shareholders. Like other co-operatives, Harvey Water charges its irrigators the minimum prices that are prudently responsible and allow it to meet all its obligations. This prudent, commercial viability approach can be contrasted with the setting of prices that a regulated monopoly would be allowed to charge.

These two different pricing approaches are recognised in the SCARM/ARMCANZ pricing principles which are now incorporated into National Competition Policy.

The SCARM/ARMCANZ principles (Figure 7.1) recognise that water businesses can charge prices consistent with returns lower than their weighted average cost of capital (WACC) provided it is prudent and commercially viable to do so.

Commercial viability requires the accumulation of capital as buffers to guard against risk. As a result, commercial viability is not generally consistent with a zero rate of return on assets. That is a positive non-zero rate of return will generally be required, albeit, a rate significantly below the WACC.

The difference between the maximum returns allowable and the rates of returns required for commercial viability is an empirical matter. A simple commercial model was developed which took into account the magnitude and timing of the dam safety program, the cost of debt funding such works and the price per ML of deliveries required in order to offset the funding costs. This analysis demonstrated that the 6% real return used in the annuity calculations is consistent with the minimum commercial requirement.

Figure 7.1 : SCARM/ARMCANZ Regulatory Pricing Principles

Regulatory pricing principles for water were endorsed by SCARM/ARMCANZ at its Hobart meeting in February 1998, following reports by the COAG Expert Group, Ernst & Young and Marsden Jacob Associates.

> *When all of this work is taken into account, it becomes clear that a prescriptive approach that can be universally applied is not practicable. Indeed to apply a rigid formula to cost recovery [as originally suggested by the COAG Expert Group] is likely to cause unintended consequences in pricing.*[52]

> *ARMCANZ agreed the guidelines should be applicable to the Council's assessments and should be endorsed by COAG as the minimum requirements. These guidelines maintain the integrity of the COAG reforms but recognise the range of circumstances peculiar to each water authority that should be considered in determining whether the full cost recovery test is met.*[53]

The core principles adopted by SCARM/ARMCANZ are:

> 4. *To avoid monopoly rents, a water business should not recover more than the operational, maintenance and administrative costs,* [incurred] *externalities, taxes or TERs* [tax equivalent regime*], provision for the cost of asset consumption and cost of capital, the latter being calculated using a WACC.*
>
> (This Guideline is often referred to as the COAG formula.)
>
> 5. *To be viable, a water business should recover, at least, the operational, maintenance and administrative costs, [incurred] externalities, taxes or TERs, not including income tax, the interest cost on debt, dividends (if any) and make provision for future asset refurbishment/replacement … Dividends should be set at a level that reflects commercial realities and stimulates a competitive market outcome.*[54]
>
> (We refer to this Guideline as "commercial viability".)

Most frequently, the CoAG formula approach results in a revenue level substantially above the level of revenue required for commercial viability, giving an upper and lower bound. However, this ranking need not always apply, especially where a small water business is required to expand substantially and rapidly or the infrastructure is lumpy and discrete, i.e., a single dam.

The integration of these two principles is that maximum prices should be equal to the higher of:

(a) the amount required to deliver the service in a commercially viable sustainable manner; and

(b) the amount derived by the TSLRIC method or the COAG formula as it is often known in the Australian water industry.[55]

Minimum prices should be no lower than those required for the business to be commercially viable/sustainable.[56]

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[52] National Competition Council (1998), *Compendium of National Competition Policy Agreements* – Second Edition, June, p. 111

[53] NCC (1998) p. 112.

[54] NCC (1998) p. 112.

[55] NCC (1998) p. 112.

[56] Recognition of the importance of commercial viability was the key feature of successful Victorian Government submissions, which were based directly on the report, "*Pricing Principles for Competitive Water Businesses*", Marsden Jacob Associates (1997)

8 RISK MANAGEMENT – PUBLIC POLICY VS CORPORATE LIABILITY

8.1 INTRODUCTION

In Australia and most western economies, there is increasing focus on risk management and prevention of loss of life. Thus there is an increasingly well-established literature on the value of a human life and increasingly systematic approaches to the evaluation of risk and the setting of risk standards.[57]

Risk standards are particularly explicit in the area of dam safety. The development of modern dam safety standards was triggered by the collapse of Titon dam and the subsequent US Federal legislation and wholesale change within the Bureau of Reclamation and Corp of Engineers. These US-led approaches have flowed into the standards and guidelines developed by ICOLD (International Committee on Large Dams) and Australia's ANCOLD (Australian National Committee on Large Dams).

These standards/guidelines set limits of tolerable and intolerable risks for large-scale loss of life. Thus, for example, a loss of life of more than 10 persons with a probability of more than 1 in a million is regarded as intolerable under the Australian guidelines. As a result, dam owners in Australia are currently expending very substantial sums on dam safety measures in order to achieve these standards (see Chapter 3, Table 3.1).[58]

8.2 UNIFORM VS DIFFERENTIAL VS NO STANDARDS

In the Australian case, at least, there are significant contrasts in what is tolerated as an acceptable level of risk. In the areas of dam safety and workplace safety the levels of acceptable risk involve very low probabilities of loss of life. In sharp contrast, a variety of high risks are accepted by governments and the community and there appears to be no systematic approach to their evaluation or a common view on what is acceptable.

A striking example of a high risk that has not been systematically approached is bushfires. For instance, in south eastern Australia over the past century there have been catastrophic bushfires, including in 1939 (Black Friday), 1983 (Ash Wednesday) and in 2003 (Canberra, Snowy Mountains and the Victorian Alps). In each case there has been substantial loss of life and a much greater loss of property, and in some cases significant effects on natural resources such national parks and water supplies. Since these events are El Niño related, the annual probability of large-scale loss of life is probably greater than 1 in 50.

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[57] See for example, Cropper, M. (1994), "Preferences for Life-Saving Programs: How the Public Discounts Time and Age", *Journal of Risk and Uncertainty*. Health and Safety Executive (HSE), United Kingdom (2001), *Reducing risks, protecting people: HSE's decision-making process*, Her Majesty's Stationery Office, Norwich. Accessed at: http://www.cabinet-office.gov.uk/risk/Policy_Risk_Assessment/departmentalriskframework.htm. and Viscusi, W.K. (1999), *Calculating Risks*, MIT Press, Massachusetts.

[58] It appears that the forward expenditure foreshadowed for dam safety is currently well in excess of $0.5 billion and that the annual expenditure is around $80 million a year.

In other areas risks may be systematically approached but the standards appear to be quite different from those set for dams and workplace safety. One striking example is, of course, road traffic accidents. We understand that black spot road accident sites have a risk of death of 10^{-4} of greater. Since 1925, when record keeping commenced, there have been over 169,000 road fatalities in Australia. Although the road fatality rate in Australia has been falling steadily since 1970, in 2002 the fatality rate was still 8.8 deaths per 100,000 population, almost 1 in 11,000.[59]

International research covering Europe and the US notes:

- wide variation in the amount of money that governments in particular are prepared to spend to save a life. Part of this variation appears to arise because some areas are covered by standards and others have a more heuristic approach;
- that the considerable diversity in attitudes to risk and acceptability and in the different amounts government and the community are prepared to pay to reduce the risk of loss of life. This raises questions as to whether these differences are fully optimal; and
- standards regulators and legislators appear to respond strongly to public perceptions of risk – or alternatively to the same factors – so that standards and regulations set widely different values on a statistical life saved by reducing risks in different areas.[60] As a result, there is a consistent observation that standards regulators (both individually and collectively), do not behave rationally in terms of seeking to set standards so as to achieve for a given budget the maximum reduction in risk.

  Standards and guidelines are strongly influenced by perceptions and perceptions can be influenced by the provision of information. While elected governments must respond to the imperative of electorate perceptions, public policy requires that governments, accept the responsibility to ensure that over time the electorate has the information required to align perceptions with reality. It follows that governments have a potentially key role in ensuring accurate information and perceptions and thus ensuring appropriate and rational standards.

In summary, where standards have been developed they appear to be differential but there is an even bigger gap between the areas which are covered by risk and safety standards, and those that are not.

The pattern of gaps and differences in approaches to setting formal standards appears to have widened during the 1990s when changes in the governance of many public institutions and instrumentalities occurred. The combination of the privatisation/ corporatisation of publicly owned utilities plus the introduction of explicit risk

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[59] Australian Transport Safety Bureau, 2003, accessed at http://www.atsb.gov.au/road/index.cfm.

[60] See Department of the Environment, Transport and the Regions (2002) *Reservoir Safety – Floods and Reservoir Safety Integration*, Main Report, prepared by Brown & Root, August; Tengs et al (1995) "Five-hundred life-saving interventions and their cost-effectiveness" *Risk Analysis*, 15(3), 369-390 and Viscusi, W.K., and Hamilton, J.T., (1999) "Are Risk Regulators Rationale?" *American Economic Review*, 89 (4), pp. 1010-1027

standards/guidelines in some areas has created different incentives, drivers and approaches to risk management and reduction from those previously existing in the public sector of each jurisdiction. In Australia, these changes occurred in the 1990s, with the 1994 as a pivotal date for both corporatisations and dam safety standards and guidelines.

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

8.3 UNIFORM VS DIFFERENTIAL vs NO STANDARDS: COMMUNITY PERCEPTIONS AND THE COURTS

The discrepancy in approaches to risk within the public sector is often explained in terms of what is acceptable to the community, and therefore the courts. As outlined in Chart 8.1, community perceptions of risk generally varies according to a range of risk characteristics such as:

- whether the risk is large-scale and catastrophic or small-scale;
- uncontrollable risk vs controllable risk;
- involuntary vs voluntary risk; and
- effects delayed vs effects immediate.

There is now a substantial body of literature on community perceptions of risk. Some of the results to emerge from that literature are that:

- communities are more concerned about catastrophic, uncontrollable and involuntary events involving large scale loss of life, than they are about multiple loss of life through small-scale, controllable, voluntary events, e.g., 9/11 vs the US road toll; and
- identified risks with very low actual probabilities are often over-estimated in terms of perception (e.g., death from attack by a white pointer shark vs death on the roads). [61]

In the case of dam safety guidelines, the concern and focus is on single event large-scale loss of life with very low probability. As noted, this contrasts sharply with the concern and approach to road accidents which involve multiple, small-scale loss of life, amounting to a large-scale loss of life cumulatively over the course of a year, each year with virtual certainty.

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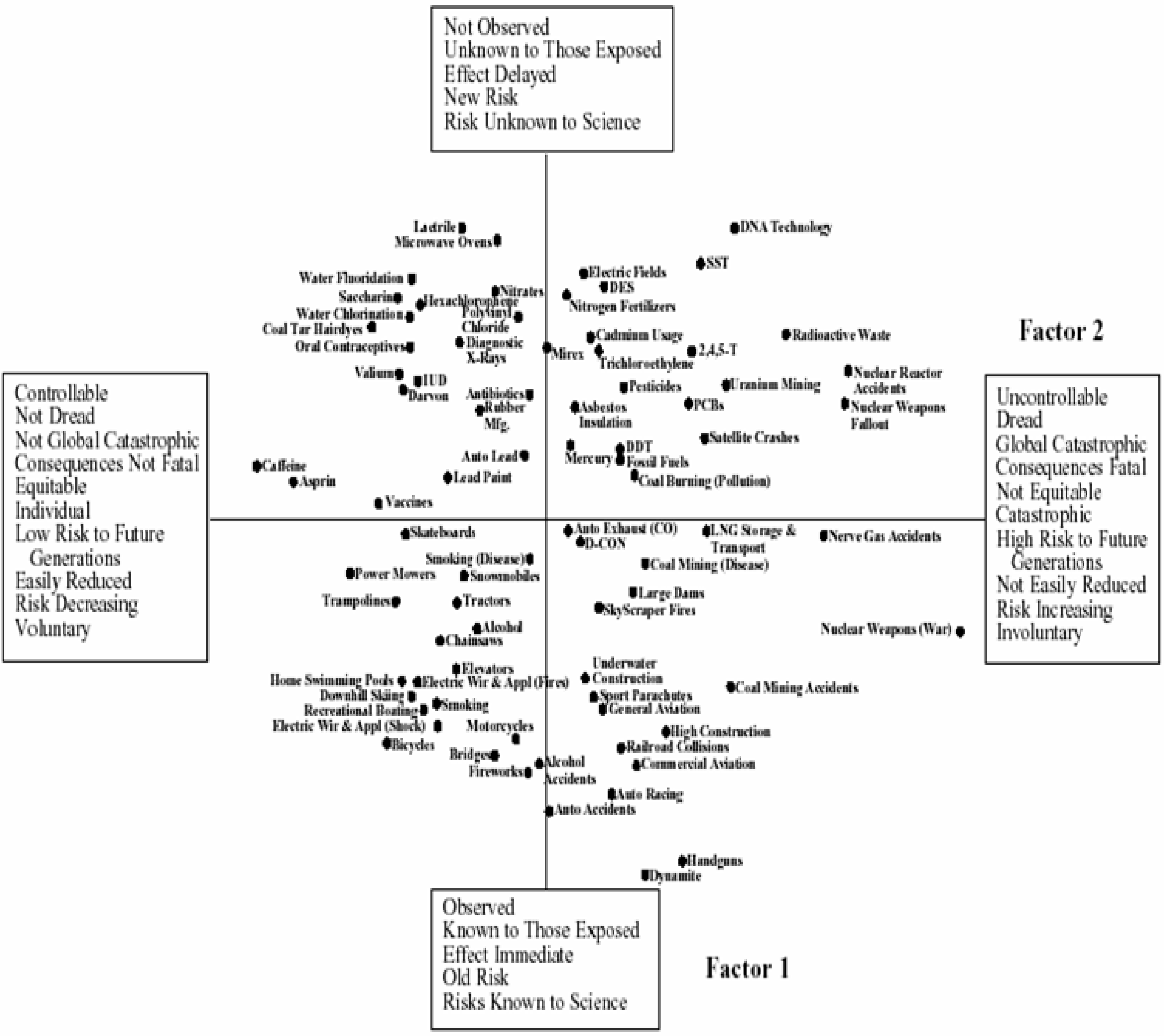
[61] See for example, Macgregor, D.G. (1996)

This contrast is typically justified with reference to community perceptions and the way courts attribute liability.

But is this the way that public policy on risk management should be set?

Chart 8.1 : Societal Risks & Risk Characteristics



Source: redrawn from Slovic (1987)[62]

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62 .

8.4 PUBLIC POLICY OBJECTIVES

Public policy is typically premised on the objectives of equity and efficiency. Putting aside the issues of property damage, it is difficult on efficiency grounds to argue that the death of a family in a road accident involves less cost than the death of a family through the collapse of a dam. Put another way, it is difficult to justify on efficiency grounds alone spending a greater sum on protecting the loss of a human life from the collapse of dam than on protecting against the loss of a human life from a road accident.

DEFRA notes

> *The question then is "At what value of CSSL* [cost per statistical life saved] *is ALARP satisfied? There is no easy answer to this question, and the answer would likely depend on the particular circumstance of each case. …OMB* [Office of Management and Budget] *show that safety measures implemented by Federal regulation in the United States have CSSL ranging from US$100,000 to US$5.7E12. The high figures reflect the emotive community response to health fears from chemicals. OMB notes that "This range shows clearly that society's resources for reducing risk are being poorly allocated." …*
>
> *Whilst the ALARP principle is clear and easily understood, its application in particular cases is difficult. There is a need to consider a wide range of social, political and environmental issues in addition to the costs of risk reduction.*[63]

This leaves the objective of equity, an objective that is perhaps less straightforward. The concept of equity starts with the premise that equally situated individuals should be treated equally. Does this mean that individuals have equal expectations to certain levels of protection from risks that are essentially outside of their control? However, this premise raises other questions, such as the extent to which exposure to a risk is voluntary or involuntary. Thus it might be argued that individuals, by and large, have a choice regarding their decision to travel on a dangerous section of road, whereas their level of choice regarding exposure to other risks, such as living downstream of a dam, may be less.

On the other hand, perhaps we should expect better protection against readily identifiable, known risks such as road accidents compared with difficult to foresee rare events.

Thus balancing public policy objectives with respect to risk may often come down to the question of whether any disparities in equity are sufficient to outweigh the observed disparities in efficiency.

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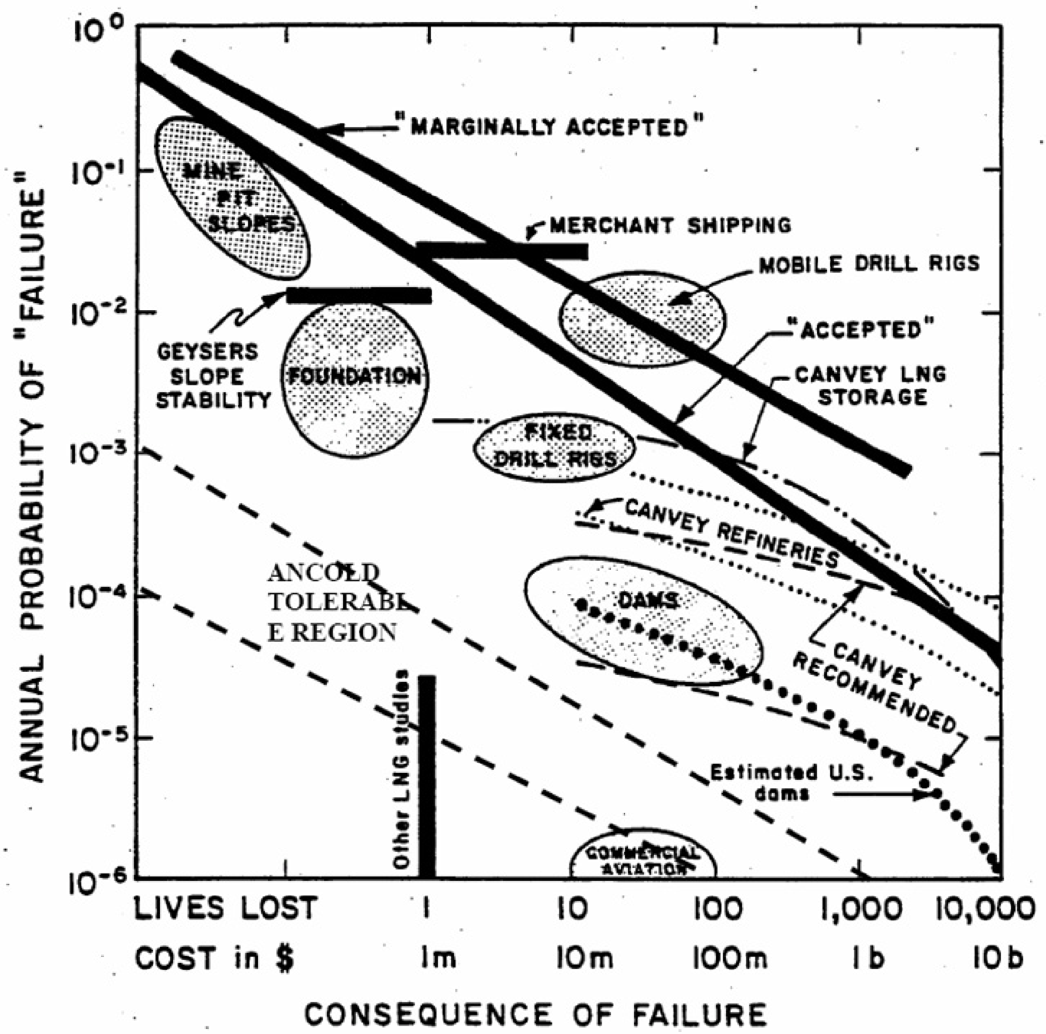
[63] DEFRA (2002), p. 116

Approaches to safety in other areas suggest that the risk standard in the ANCOLD guidelines is significantly more demanding than the standards applied elsewhere. For example, the UK Department of Environment, Transport and the Regions (DEFRA) plotted annual probabilities of risks in various industries on a F-N diagram and the published boundaries for a tolerable region (Chart 8.2).

Chart 8.2 : Risks in Other Industries



Source: DEFRA (2002) Appendix H, p. 177

DEFRA highlight

- *the range of annual probability over the tolerable range varies between one and three orders of magnitude, depending on the originator of the curve*
- *some authors show that LLOL in excess of some magnitude as being 'High risk zone', where the best methods should be used to assess and manage risk, rather than accepting the concept of a tolerable region. This upper limit of tolerable LLOL varied from 20 casualties to 1000*

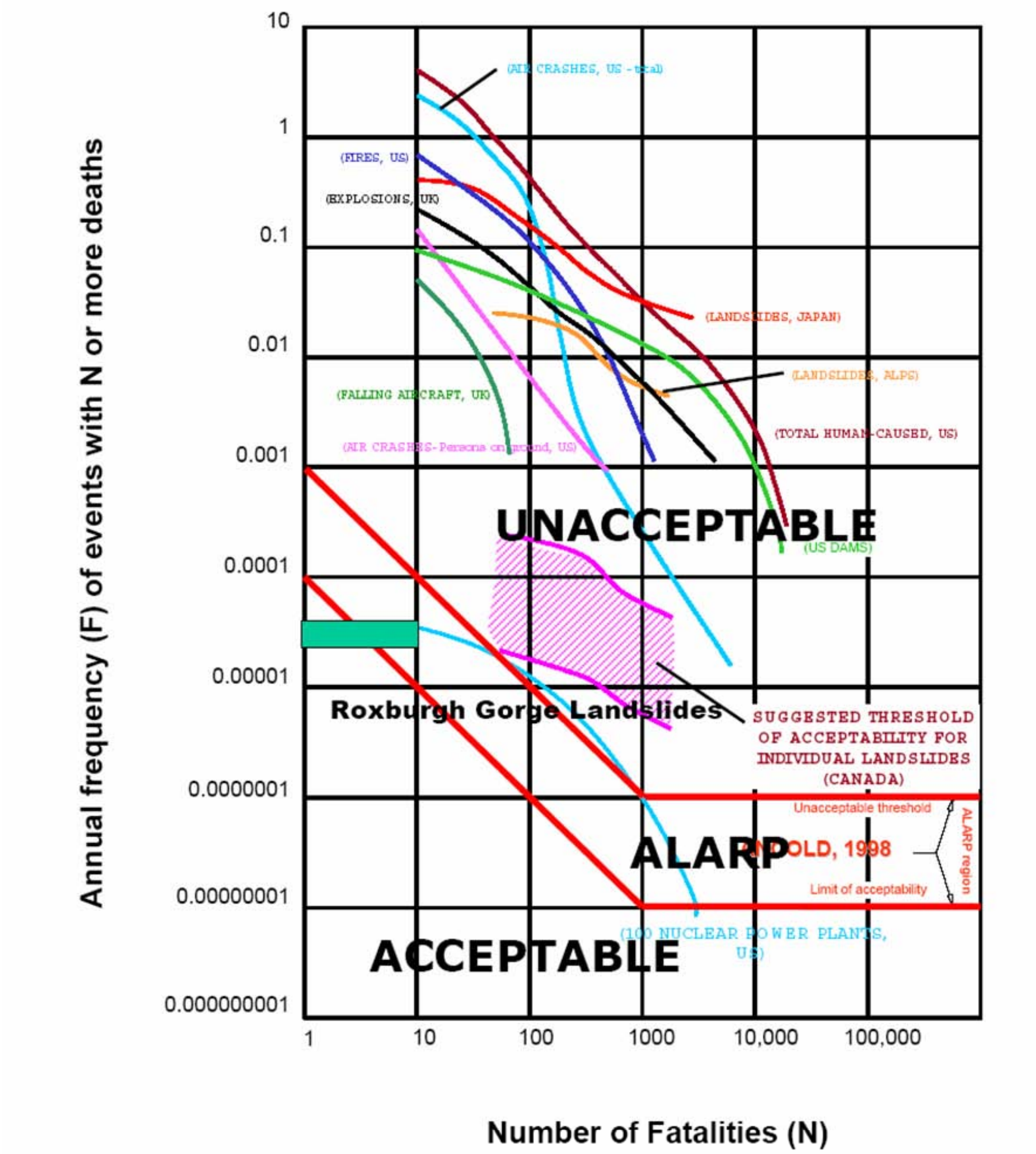
- *ANCOLD truncate the curves at a lower annual probability of* 10^{-6} *and* 10^{-7}, *on the basis that "it is not possible, given the state of the art, to reliably estimate annual probabilities of failure to such very low levels" (page 6 of Commentary).*

These indicate that historically it has been considered that societal concerns suggest that the annual probability of failure should reduce by an order of magnitude for every order of magnitude increase in fatalities. Whether this is practicable for dams, and whether this is still the view of policy makers is uncertain.[64]

Similarly, evidence on the relative situation of the ANCOLD criteria was provided to the review by the Otago Regional Council of resource consents for the ongoing operation of the dams and their related activities by Contact Energy which runs the Clyde, Roxburgh and Hawea dams situated on the Clutha River/Mata-Au in Central Otago (Chart 8.3).

[64] DEFRA (2002) p. 113

Chart 8.3 : ANCOLD Risk Criteria vs Other Events



Source: http://contactconsents.orc.govt.nz/evidence/Attachment_10-FN_curve.pdf

8.5 PUBLIC POLICY vs CORPORATE RESPONSIBILITY

For the objective of minimising corporate liability for risk, there is no doubt that the directors of a corporation, whether privately or publicly owned, will and should take account of the way the courts will attribute liability.

A foremost motivation of a director will be to minimise personal and corporate liabilities. However, minimising liability is not the same as minimising risk.

Public policy ought to be formulated in terms of efficiency and equity, i.e., on the basis of minimising the net costs and inequities of risk in the community/economy. Public policy should not be focussed solely on protecting a public utility or protecting a particular arm of government from legal liability.

On the other hand we understand the revised but not finally agreed ANCOLD guidelines have recognised that an owner, whilst responsible for the safety of a dam or dams, does not have a charter to act on behalf of society and is not in a position to make a judgement that such risks can be tolerated on the basis of the "*wider interests of society*". Such a judgement is a matter for government.

One of the tasks in defining corporate responsibilities and public sector governance models in particular, is to balance the public policy objective with the responsibilities to shareholders. Management will have its own views and objectives in managing risks and managing their liabilities.

There appears to be a need to distinguish between risk management from a public policy point of view and risk management from a liability management perspective. In specialised areas of risk assessment and risk management (such as dam safety) however, the setting of standards and guidelines on acceptable risks is strongly influenced by specialists employed/engaged by the operational entities (such as the utilities).

In the case of the application of dam safety guidelines, there appears to be little or no distinction drawn between public policy objectives and the minimisation of risk of liability to dam owners. Indeed, since most, if not all members of standards/guideline setting committees are drawn from or are professionals, who are dependent upon the dam owners, it would be surprising if such a distinction were to occur naturally.

8.6 RISK MANAGEMENT – THE NEED FOR A WHOLE-OF-GOVERNMENT APPROACH?

In general terms, the issue of public policy vs corporate liability approaches to risk management becomes relevant when the 'user pays' principle is not fully applied and the government must therefore pick up some or all of the costs of meeting safety standards. This is the situation in the South West where a substantial proportion of the costs of meeting dam safety standards will be borne by the State Government. In determining the efficiency and equity of meeting those standards – but all governments face budget constraints. The question therefore arises as to whether priorities and timetables for dam safety should be set within a whole-of-government risk assessment and management framework – a framework in which the government's objectives, taking into account budgetary constraints, may be to prioritise across all risk reduction expenditures to get the 'biggest bang for its buck' i.e., spending each dollar where it is most effective in reducing loss of life throughout the community, across a whole range of hazards.

A whole-of-government approach to risk assessment and management is currently taken in the United Kingdom, where every major government department has a risk management policy that is consistent with a common framework. Co-ordination of approaches to risk management is undertaken through a strategy unit in the Cabinet Office[65]. The aim of this co-ordination is to harmonise activities and approaches, with the emphasis being on understanding if and why there are different approaches between departments and activities to risk management and to explain those differences to the community and stakeholder groups[66]. To assist with the coordination, a Risk Support Team has also been set up in HM Treasury to support a two-year risk management programme.

Another government body in the UK with a key role in risk assessment and management is the Health and Safety Executive (HSE) which, in conjunction with the Health and Safety Commission (HSC), is responsible for the regulation of almost all risks to health and safety arising from work-related activities. The HSE has published a major document setting out the basis for its decision-making processes on risk[67]. A key section of the document are the principles or criteria used by the HSE for reaching decisions on health and safety standards and other approaches to risk management. In summary these principles comprise:

- an **equity-based** criterion, which starts with the premise that all individuals have unconditional rights to certain levels of protection;
- a **utility-based** criterion, which compares the incremental benefits of the measures to prevent injury or loss of life, with the cost of the measures; and
- a **technology-based** criterion which focuses on the use of 'state of the art' risk control measures.[68]

Although occupational health and safety is not directly relevant to the issue of dam safety, the approach taken by the UK Cabinet Office and HSE to achieving a whole of government approach to risk management appears applicable to all governments including the Government of Western Australia.

8.7 DIRECTING & PROTECTING DIRECTORS

Even with a whole-of-government approach to risk assessment and management in place, there still remains the issue of how to deal with the possible dichotomy between the need for directors to take a corporate liability approach to risk management and the responsibility of governments and Ministers to pursue public policy objectives.

One way around this problem may be for the government, through legislation or other means, to assume liability for particular facilities or infrastructure from the controlling

[65] See Cabinet Office, Strategy Unit, United Kingdom (2002) *Risk: Improving government's capability to handle risk and uncertainty*, Cabinet Office, London.

[66] Dr Leonard S Levy, MRC Institute of Environment and Health, University of Leicester, *pers com.*, 5 March 2003.

[67] HSE (2001) *Reducing Risks, Protecting People: HSE's Decision-making Process*

[68] HSE (2001) pp. 40-41.

authority or public corporation, in the event of infrastructure failure. This may be a feasible approach for state-owned enterprises.

State Owned Corporations (SOC) Acts in many states in Australia allow for the portfolio Minister to require a statutory SOC to cease to perform activities where the Board considers that it is not in the commercial interests of the SOC to do so. For example, Section 11 of the NSW *State Owned Corporations Act 1989* states that:

> *"If a Minister wishes a company SOC to perform activities, or to cease to perform activities, or not to perform activities, in circumstances where the board considers that it is not in the commercial interests of the SOC to do so, that Minister with the approval of the Treasurer may, by written notice to the board, direct the SOC to do so in accordance with any requirements set out or referred to in the notice".*

Similarly, under Section 64 (1) of the Western Australian *Water Corporation Act 1995* the Minister for Water Resources may:

> *".. give directions in writing to the Corporation generally with respect to the performance of its functions and, subject to Section 65, the Corporation is to give effect to any such direction".* [69]

Thus it is conceivable, within a whole-of-government risk assessment and management framework, that the Minister for Water Resources, in order to achieve a whole-of-government approach to risk management, could direct that, under specified conditions, liability in the event of dam failure or other hazard associated with dams be borne by the State Government.

However, a word of caution: while the directions option is feasible, it is less robust than the legislative option. This is so because:

- first, in principle legislative guidance is more transparent and commands higher priority than Ministerial direction; and
- second, Ministerial directions under SOC Acts can not relieve the SOC of responsibilities dictated by other legislation.[70]

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[69] In August 1996 this provision was put into effect when the Minister directed that:

> *The provision of irrigation services known as the South West Irrigation District currently conducted by the Water Corporation be transferred to the South West Irrigation Management Co-operative and the South West Irrigation Asset Co-operative…*

See, Water Corporation (Western Australia), (1997), *Annual Report 1996-97*. p.33.

[70] Requirements under legislation and developed through common law cannot be overturned by a direction. Reinforcing this, SOC Acts specifically limit the scope of directions that Ministers can issue.

As a result, legislative guidance should be strongly preferred over Ministerial direction as a method of ensuring better whole-of-government approaches to risk.

In conclusion, through raising the possibility of a whole of government approach to risk management, we are not suggesting that this will provide a 'solution' to the issue of dam safety in the South West. Nevertheless, there are clear tensions in the current approach to risk management in Western Australia. Addressing these tensions is likely to lead to better outcomes, both with respect to dam safety and other public risk management issues. We note that the State Treasurer has recently signalled a move in this direction by foreshadowing processes to ensure a common approach to setting capital expenditure priorities and trade offs on a whole of government basis rather than within individual entities.

9 RECOMMENDATIONS & DIRECTIONS

The Terms of Reference for this review require:

- an assessment of the relevance of the interpretation and application of ANCOLD 1994 guidelines to irrigation dams in other parts of Australia to this Dam Safety Program;
- an evaluation of the risk assessment processes used and the risk levels adopted.
- an assessment of the proposed remedial works program to upgrade the safety of South West (Irrigation) Dams to comply with the Bulk Water Supply Agreement;
- determination of whether provisions of the Bulk Water Supply Agreement, in relation to the Dam Safety Program, have been applied;
- discussion of the long-term financial commitment being sought under the Bulk Water Supply Agreement in relation to the short-term (5 year) nature of the SWIC licence and advise on appropriate arrangements for implementation and ongoing management; and
- recommendations for the apportioning costs of the dam safety works between beneficiaries.

We summarise the conclusions, recommendations and future directions on each of these below.

9.1 RELEVANCE OF ANCOLD GUIDELINES

In the absence of specific state legislation on dam safety, the ANCOLD Guidelines provide the national community standard against which dam safety must be assessed in Western Australia. These Guidelines reflect judgements on the limits of tolerability for societal risk and individual loss of life. They also provide a framework for assessing risk in all major areas.

Responsible dam owners must also observe the separate ALARP criteria i.e., whether the risks have been reduced as low as reasonably possible.

The ALARP criterion operates only where assessed risks are estimated to be tolerable. That is, benefit cost calculations do not enter consideration until the standards set by the limits of tolerability have been met. That is, regardless of cost, the risk guidelines established by ANCOLD provide the national community standard and need to be followed by prudent directors and management. However, where the costs-benefit ratio is favourable, risk should be lowered further than indicated by the ANCOLD guidelines. Without separate legislation to protect the directors and management of dam owners, this asymmetry will continue.

For immediate purposes of this study, this asymmetry is unavoidable.

There is considerable international evidence, and some Australian evidence, to suggest that areas covered by specific safety standards set very different risk levels to areas of government activity not covered by explicit standards. This divergence is most evident in the amount of money that governments are observed to spend to save a life in different areas. We are not aware that the Western Australian Government has made any attempt to set a comprehensive approach to risk reduction and risk management. We return to this issue below.

Recommendation

1. The Western Australian Government and Water Corporation should consider the consistency of dam safety standards and its other approaches to risk reduction and risk management.

9.2 RISK ASSESSMENT PROCESSES & RISK LEVELS

Water Corporation currently utilises a process that compares favourably with current Australian best practice in dam safety management. They have adopted risk-based decision-making and a stated objective of eventually reaching compliance with modern ANCOLD dam engineering standards. However, our review has identified opportunities for enhancements in several elements of the overall process.

Recommendation

2. To meet current best practice, Water Corporation's dam safety program should:

- **involve stakeholders at key junctures in the development of the dam safety program to assist in communicating, testing, validating and prioritising risk reduction, and the prioritisation of works and strategies;**
- **strengthen and broaden the existing use of expert reviews and ensure the expert review process is transparent and that there are robust audit and feedback mechanisms to ensure resolution of outstanding issues;**
- **make substantially greater use of detailed risk assessment techniques to update and refine its risk profile as design reviews and concept designs are completed for each dam. This may affect the prioritisation and urgency of works, and help support critical funding decisions; and**
- **consistent with capital constraints, consider interim risk reduction works to achieve risk levels below the ANCOLD tolerability limit.**

9.3 ENGINEERING INPUTS & ASSESSMENT OF REMEDIAL WORKS PROGRAM

9.3.1 GEOTECHNICAL ASSESSMENTS

Piping Risk

In terms of Waroona Dam, the study found that the proposed remedial works will replace the current drainage system with a more effective and reliable system that prudently satisfies modern dam design standards.

We acknowledge that Water Corporation and its consultants strongly believed that the geotechnical risks at Waroona are intolerable and required urgent works to reduce this risk However, careful review of the documentation provided to us and independent checks of key issues have not provided a compelling case for the urgency of the works, especially considering the required water losses during the current drought. We do not question the need for the works or their effectiveness in bringing the dam to a modern engineering standard. Although the case for staging the works has been addressed and dismissed as inefficient, we were not convinced.

Based on the conditions reported to us to be exposed during construction, a detailed risk assessment including expert reviewers and key stakeholders, such as Harvey Water, would have helped build consensus about the urgency of the works.

Similarly, the study concluded that Water Corporation's assessment that Waroona Dam does not possess an adequate factor of safety against downstream slope stability failure under seepage conditions was overly conservative. This was due to the adoption of pore pressures that represented worst case conditions rather than best estimates that would normally be used in risk assessment.

Recommendation

3. Consistent with best practice, for design purposes, prudently conservative, estimates of relevant parameters should be used. For risk assessment, best estimates of relevant parameters should be used.

The **remedial works program** for the other dams has not progressed to the same stage as for the Waroona Dam. However, based on the assessments undertaken, the following insights are provided:

- for **Drakesbrook Dam**, monitoring data indicate the existence of high pore pressures in the downstream shoulder and we concur with Geo-Eng's assessment that this is most likely due to seepage over the top of the puddle core. The piping risk has been assessed to be unacceptable by Geo-Eng based on the historic performance method. In this case, a more detailed piping assessment using event tree methods is likely to support this conclusion because of the increased risk associated with piping above the top of the puddle core under normal, flood and earthquake loading conditions;

- **Stirling Dam** with its unusual composite cross-section, with puddle core type zoning in the lower half of the dam and rockfill in the upper half presents a piping risk due to its lack of filters. The preliminary upgrade works for Stirling Dam do not currently address this potential deficiency;

Recommendation

4. A detailed investigation and assessment of piping risk at Stirling should be undertaken.

- the main embankment of Logue Brook Dam is deficient compared with standards criteria because the chimney filter does not extend to Fully Supply level. The saddle dam is also deficient in that it has no chimney filter and only a toe drain. These deficiencies increase the risk of piping through the dam under normal, earthquake and flood-loading conditions. Whilst it is anticipated that a low piping risk exists, it is recommended that a more detailed assessment of the piping potential be undertaken;

Recommendation

5. It is recommended that a more detailed assessment of the piping potential be undertaken for the Logue Brook Dam.

- the methodology assumptions and conclusion from the stability assessments carried out as part of Water Corporation's Design Review studies for the Stirling, Logue Brook, Samson Brook and Drakesbrook Dams appear to be based on sound engineering principles; and
- there are several concerns with the stability of the Wellington Dam under extreme flood and seismic loading, which have been enunciated clearly by Geo-Eng and Graeme Bell, including:
  - cracking through the original dam;
  - uplift pressures;
  - disadvantageous joint orientation in the foundation rock;
  - cracking at the base of the original dam; and
  - potential AAR induced cracking.

We endorse Geo-Eng's recommendations for reducing the risk in the short term, which include drain cleaning, increased instrumentation and increased frequency of measurements. However, given the relatively high risk of failure of the dam under moderate flood conditions even after the drains are cleaned, consideration should be given to the implementation of the additional measures suggested by Bell to further reduce the risk.

Recommendation

6. For Wellington Dam, consideration should be given to the implementation of additional measures to reduce further the risk including:

- **developing a preliminary emergency preparedness plan with some early warning systems defined;**
- **deepening the existing foundation drainage curtain; and**
- **lowering the present operating FSL.**

The primary dam safety issues associated with the outlet works include:

- access to operate guard gates and valves during an emergency;
- seismic stability of outlet towers;
- piping along unprotected conduits; and
- deterioration of conduits leading to potential leakage and collapse.

Of the four, the first two issues are significant for Waroona and Logue Brook because the access ladders are no longer present and the seismic stability is marginal. Seismic stability of the tower at Stirling is also a concern. Seepage has been observed along the conduit at Samson Brook, but the flow is very small and currently not a concern. Deterioration of the cast iron conduit at Drakesbrook is a concern.

An important driver to upgrade the towers at Waroona and Logue Brook is normal operations and maintenance.

9.3.2 Hydrological Assessments

The procedures used to characterise hydrologic risk in the South West Dams are broadly consistent with the ARR99 guidelines. However, there are a number of areas in which the adopted procedures differ from design practice used commonly in other parts of Australia. The main areas of departure from common design practice are related to the:

- seasonal variation in the salient flood producing mechanisms;
- the manner in which rainfall losses are estimated; and,
- the estimation of baseflows associated with extreme events.

There are sound theoretical reasons for tailoring the flood estimation approaches to the unique characteristics found in this region, and it is clear that the practitioners involved in estimating the floods for these dams have given the relevant issues careful thought.

Overall, it is considered that the general approaches and procedures used in the studies are appropriate, and that the main points of departure from established practice are conceptually desirable. However, there are a number of areas in which it is considered that the accuracy and defensibility of the estimates could be improved.

Design Rainfalls

It is recommended that some regional analysis be undertaken to derive design information on "pre-burst" rainfalls. This would assist the validation of the loss models (when used in conjunction with independent estimates of design floods) and would aid extrapolation of the results to extreme events.

It is further recommended that some regional analysis be undertaken to identify the seasonality of 1 in 100 AEP short duration rainfalls (six hours and less) as at present it is not clear on what basis these have been derived.

Seasonality

At present the analyses are based on dividing the year into two seasons (October-April, May-September). Preliminary analyses indicate that consideration of four seasons rather than two may be more appropriate (the occurrence of rainfall maxima is divided into summer and winter, and other inputs are divided into four seasons, namely Oct-Dec, Jan-Apr, May-Jun, Jul-Sep). Exploratory investigation indicates that (if the model is adequately calibrated) there will perhaps be little difference in the magnitude of the inflow flood, but there may be an increase in the likelihood of overtopping due to the seasonal distribution of storage level.

Absorption Losses

Absorption losses associated with extreme rainfall events are generally assumed to be low or zero in many parts of Australia. In addition, it is common to assume that loss rates are constant throughout the duration of the rainfall event.

By contrast, the loss values assumed for the South West catchments are far higher than used elsewhere in Australia, and they are allowed to vary over the duration of the event. Although the conceptual basis of the loss modelling used is appreciably different to that used elsewhere in Australia, it appears to be well founded on empirical evidence and appropriate to the unique characteristics of the region. The use of field data to derive the soil water storage characteristics and their spatial variation for different landform classes, also seems to be a strength of the adopted approach.

However, while the conceptual basis of the method is defensible, it is considered that the manner in which it is applied in practice could be improved upon. There are several aspects to this:

- there are some conceptual difficulties with the manner in which the model is calibrated and then used to estimate design floods; and
- the model at present is based on the use of fixed seasonal initial moisture conditions, and preliminary analyses indicate that different (possibly lower) design flood estimates might be obtained when used with a distribution of values.

There are ways in which the available information could be better incorporated to minimise the difficulties associated with the loss modelling, which are outlined in Appendix A.

Parameter Identification

At present the studies have relied solely on the ability of the model to reproduce historic flood events that are around 1/10 to 1/80 the magnitude of the final PMP Design Floods. It is considered that better use could be made of regional information, particularly with respect to comparing the results obtained using independent methods (such as those based on at-site/regional flood frequency analyses). More use could be made of the existing information of the seasonal variation of rainfall events

Initial Storage Assumptions

At present all studies have assumed that the initial water level in the reservoir will be at Full Supply level. This assumption may be unnecessarily conservative, and it is possible for some of the storages the consideration of initial drawdown will reduce the estimated likelihood of overtopping failure.

Summary

The methods used to estimate extreme floods in this region depart in some significant respects from established practice used elsewhere in Australia. Overall, it is considered that there is strong theoretical justification for incorporating seasonality and the adopted loss model, however the manner these considerations are dealt with in practice could be improved upon.

It is difficult to predict what the overall impact on the estimated likelihood of overtopping failure would be if the salient issues were addressed. It is possible that resolution of the most important issues will result in lower estimates of overtopping failure, though the main uncertainty here is the impact arising from review of the parameter values using independent estimates of (more frequent) design floods.

While some of the additional investigations discussed in this review may be considered onerous to undertake for a single dam, the benefits can be attributed to the whole portfolio of South West Dams and thus they are easily justified.

A summary of the nature and assessed degree of importance of the hydrological issues raised is presented in Table 9.1.

Table 9.1 : Summary of nature and degree of importance of hydrological issues raised

Issue raised	Likely impact on results if issue addressed	Degree of Importance to defensibility of results
Reconciliation of seasonal rainfall-based flood estimates with at-site/regional flood quartiles	Unknown impact on flood magnitude, but greater confidence in results and increased defensibility.	High to Very High
Initial reservoir level	Estimated likelihood of overtopping will either remain unchanged or will reduce (particularly Logue Brook, and any other dam that is likely to be drawn down below full supply level)	High to Very High
Manner in which baseflow incorporated	Flood peaks and estimated likelihood of overtopping may reduce	High
Initial soil moisture conditions treated as a variable rather than as a fixed value	Flood peaks and estimated likelihood of overtopping may reduce	High
Analysis based on four rather than two seasons	Unclear, though possibly a net decrease in estimated likelihood of overtopping due to seasonal interaction with initial storage level	Medium to High
Incorporation of additional information on seasonality of short-duration rainfalls	Unknown impact on flood magnitude, but greater confidence in results and increased defensibility.	Medium
Incorporation of pre-burst rainfall proportions for all durations	If model adequately calibrated then this may have little impact on results, but will provide greater defensibility of results in cases where calibration data are limited.	Medium
Use of sample of temporal patterns rather than single fixed pattern	Uncertain impact on flood magnitude, though of high importance in estimating the Probable Maximum Flood (as distinct from the PMP Design Flood).	Medium (for probabilistic floods) High (for PMF)
Incorporation of long duration CRC-FORGE rainfalls	Experience elsewhere indicates that estimates of overtopping likelihood generally reduce (though not always the case), though will provide greater defensibility of results for dams where longer durations are relevant.	Low (for most storages) High (certainly for Wellington Dam, and others where initial drawdown is important)
Treatment of sensitivity analyses	At present results for climate change and parameter uncertainty are misleading	Low

Recommendation

7. **The accuracy and defensibility of hydrological assessments and estimates issued in Water Corporation assessments of hydrological risks should be improved, with particular attention to:**
   - **design rainfalls;**
   - **seasonality of;**
   - **absorption losses;**
   - **parameter identification; and**
   - **initial storage assumption**.

9.3.3 CONSEQUENCE ASSESSMENT

In summary, our review of the consequences reveals:

- the general approach adopted for dambreak analysis is appropriate, though there are some aspects (primarily related to floodplain storage and the modelling of internal and external boundaries) that could be further investigated and/or improved upon;
- the procedure used to estimate the loss of life has not been formally documented and this situation should be rectified. Inspection of the calculation spreadsheets indicate the presence of some (minor) calculation errors and the criteria used to specify high flood severity appear to differ from published procedures. In addition, it is suggested that the manner in which the different exposure factors are treated could be improved upon, and anecdotal discrepancies in estimates of the population at risk should be investigated;
- the environmental impacts of dam failure were not included in the consequence assessment; such impacts can be substantial and can provide additional justification for mitigation measures; and
- in general, the economic consequences have not been undertaken in a consistent nor particularly thorough manner, and it is suggested that improvements to this component will help identify the optimum risk-reduction pathway across the portfolio of South West Dams.

Recommendation

8. The accuracy, completeness and documentation of consequence assessment should be improved with particular attention to:

- **flood plain storage and boundaries;**
- **loss of life estimation; and**
- **environmental and economic impacts.**

9.4 AS IF THEY OWNED THE ASSETS

Consistent with the principle enunciated in the 1996 Cabinet Submission that the prices for bulk water should be set as if the irrigators owned the assets, we consider that the efficient cost of the dam safety upgrades should be defined in the same way, and that the resulting differences, although unquantifiable, are likely to have been material, at least for Waroona and possibly for the supply system as a whole.

We consider that if the irrigators had indeed owned the dams, ANCOLD standards would have provided the same light on the hill, but there would have been a finer and different assessment of risk, much higher levels of stakeholder understanding and acceptance of the financial consequences, some different solutions including greater use of interim and management solutions with the completion of the final program pushed out over a longer period.

As a result, Harvey Water as a dam owner would likely behave with a very acute awareness of its capital constraints and the opportunity costs of its available capital. This situation is not unique. It is clearly seen in the revealed behaviour of Goulburn-Murray Water, Melbourne Water and others and confirmed by our discussions with senior officers of the respective organisations.

Like Goulburn-Murray Water, Harvey Water could be expected to:

- endorse the movement to achieve ANCOLD Guidelines over a reasonable time period;
- use transparent and well-documented expert reviews and participatory workshops to validate a conservative but responsible approach to safety upgrade expenditures;
- explore thoroughly interim and staged solutions;
- act expeditiously to address *prima facie* and confirmed high risks;
- check carefully hazard and risk assessments to ensure that no expenditure is undertaken unnecessarily or ahead or behind of priority;
- undertake extensive consultation and workshopping with its customers to ensure that the agreed program of works and initiatives is fully accepted as are its financial consequences;
- apply special levies to raise funding before seeking debt funding to undertake the required remedial initiatives and works; and
- implement interim and staged solutions.

The indicated differences between a dam safety program developed and implemented by the Corporation compared with a program developed by Harvey Water, reinforce the need for best practice approaches to be adopted for the remaining five dams.

Recommendation

9. **In developing future risk reduction programs, Water Corporation should examine the issues and strategic options from the perspective of all major stakeholders and involve them in the process. It should also recognise the impacts of capital constraints on the optimal rate and path of risk reduction.**

9.5 BULK WATER SUPPLY AGREEMENT

The BWSA foreshadows expenditures on dam safety upgrades and the expectation that irrigators will pay part of the cost. Consistent with the uncertainty on the extent and cost of remedial works required, the relevant section of the BWSA is not prescriptive and leaves considerable discretion in the negotiation and decision process.

Nothing that has occurred to date appears to contravene the relevant section of the BSWA.

9.6 LONG-TERM COMMITMENT TO FUNDING & LICENCES

At the current time, the bulk water licence held by Harvey Water has a five-year duration. At the same time, Harvey Water is being asked to fund at least part of the cost of dam safety upgrades which will contribute to the life of the dams and take an assumed eighty years to pay.

A key question: Is this apparent mismatch material?

First, the funding mismatch need not be material provided funding arrangements are sensible. The presumption is that other beneficiaries will be required to pay at least part of the total safety upgrade program and that other water users will pay the same, or equivalent, per ML charge. In other words, if Harvey Water were to sell or trade part of its bulk licence, then the annual liability for the safety upgrade would transfer to the purchaser, whether this be Water Corporation if the water is used for consumptive purposes, or the Waters & Rivers Commission if the water is taken back for environmental flows.

Second, funding of safety upgrades by water users needs to consider whether per ML charges are set on the basis of nominal allocations or on the basis of annual or average deliveries. This is a particular issue in the South West where average deliveries have been not much more than half the nominal allocation.

The large gap between nominal allocations and effective allocations is also an issue which Harvey Water will need to consider with the forthcoming renewal of its existing licence providing an opportunity to resolve or confirm matters.

Third, the five-year term of Harvey Water's licence from the Water & Rivers Commission appears to be short by the standards of other irrigation companies in Australia. All or most irrigation companies/authorities hold bulk licences, but typically with a term of ten or fifteen years before renewal. The role of the renewal is typically to allow conditions protecting third party interests and the environment to be reviewed. This includes a review of the adequacy of environmental flows. While conditions may be changed there is no presumption that the nominal volumes will be reduced and a presumption that any change in effective volumes will be limited. (The largest single change in effective volumes in Australia is the Namoi where a 14% reduction occurred due to acknowledged over-exploitation of the resource and the desire to return to sustainable yield.)

There is no apparent reason why Harvey Water's licence should be shorter than the licence of its counterparts elsewhere in Australia. We note that these are likely to be addressed by Commonwealth and State Governments following recent CoAG discussions.

Recommendation

10. The period of Harvey Water's licence should be reviewed with the intent to bring this period into line with other irrigation licences.

9.7 ANALYSIS OF PRICE & AFFORDABILITY ISSUES

As noted in Section 7.5, if irrigators were to fund 100% of their share (based on system yield) of the dam safety costs, this would equate to a $57 per ML increase in the delivered cost of water. In turn, this would represent an seventeen-fold increase in the effective farm-gate cost of bulk water and represent around a 120% increase in the total delivered cost of water.

In order to better understand the distributional impacts of increased prices due to the recovery of dam safety upgrade costs, a detailed customer incidence analysis was undertaken. This analysis utilised data provided by Harvey Water on customer entitlements and usage.[71] Separate incidence analysis models were developed for each of the three systems which enabled the impact of any percentage recovery of the designated irrigator share of dam safety upgrade costs to be analysed on an individual customer basis. The models also enabled the impacts of uniform pricing (i.e., current practice) to be compared with the impacts on customers should Harvey Water move to allocate dam safety upgrade costs on an individual system basis (i.e., not equalise the costs across the total customer base).

The distributional consequences are assessed both in terms of percentage and dollar increase in water bills.

An immediate conclusion based on affordability alone is that irrigators should not be asked to contribute 100% of the costs attributable to irrigation. We have therefore examined the impacts of the irrigator share of relevant dam safety upgrade costs varying from 25% to 75%. These are illustrated below in Charts 9.1 to 9.6 where the odd numbered charts relate to the percentage increase in bills and the even numbered charts relate to the dollar increase in bills. Chart 9.7 provides a summary set of statistics relating to each cost sharing scenario.

[71] Usage data for Waroona and Collie irrigation areas is based on five-year average whilst usage for Harvey is based on 2000/01 season due to data extraction problems.

Chart 9.1: Customer Impacts - Percentage Increase in Water Bills Assuming 25% of Cost Allocated to Irrigators

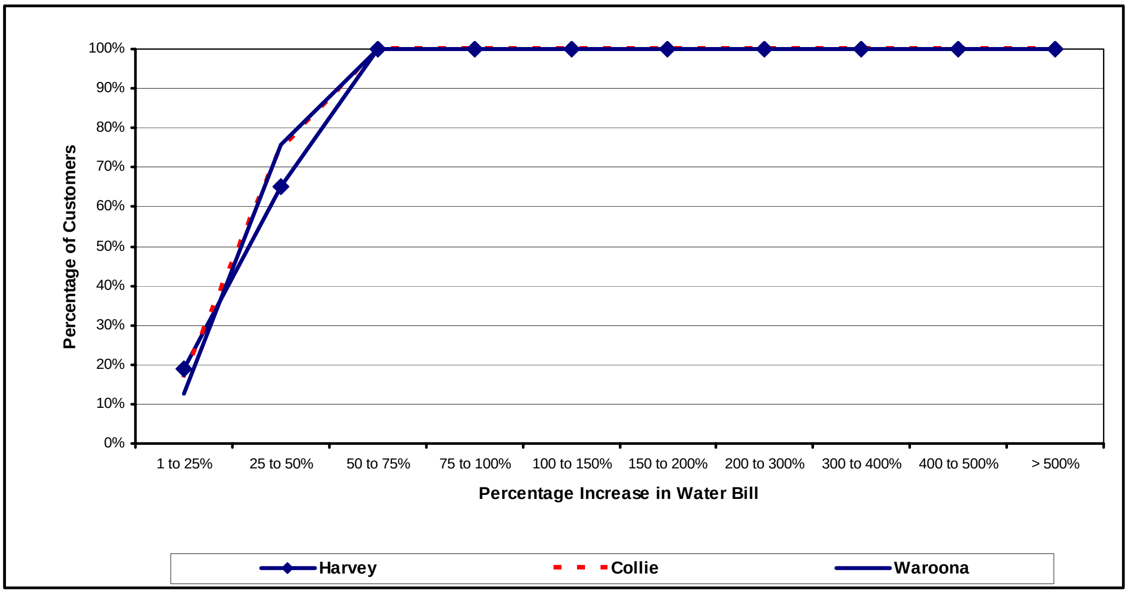


Chart 9.2: Customer Impacts - Dollar Increase in Water Bills Assuming 25% of Cost Allocated to Irrigators

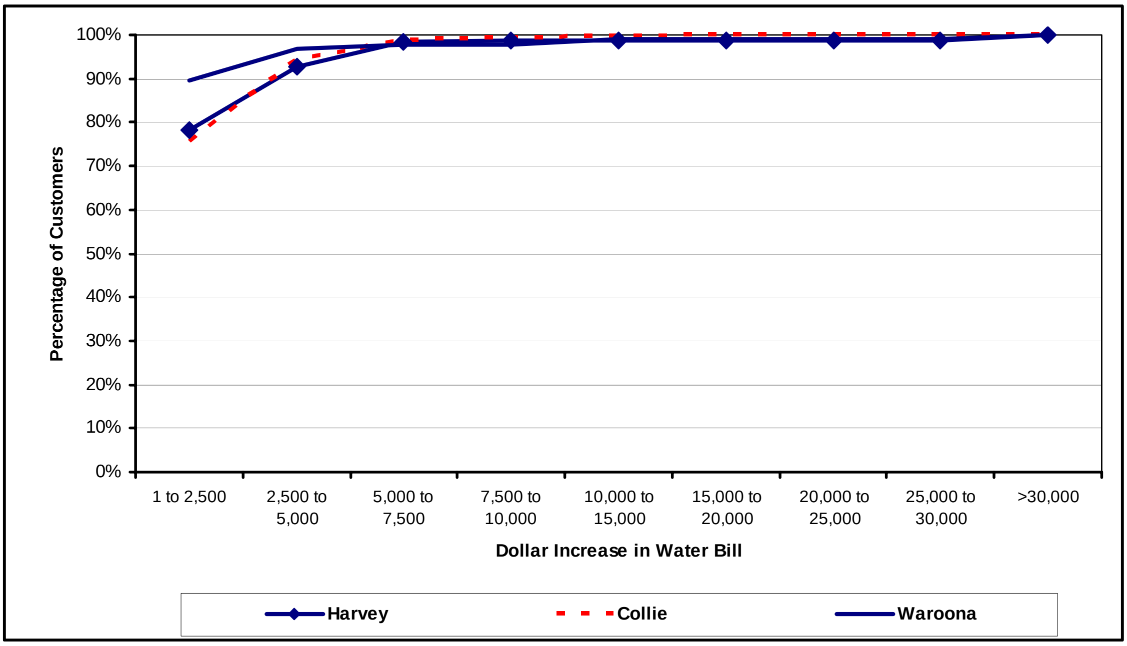


Chart 9.3 : Customer Impacts - Percentage Increase in Water Bills Assuming 50% of Cost Allocated to Irrigators

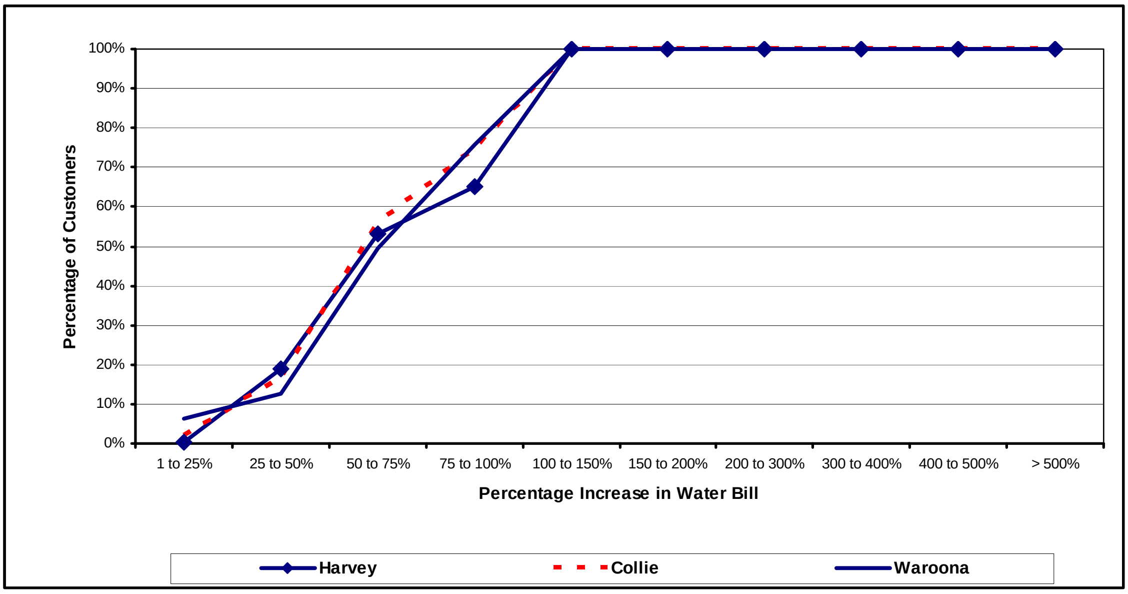


Chart 9.4: Customer Impacts - Dollar Increase in Water Bills Assuming 50% of Cost Allocated to Irrigators

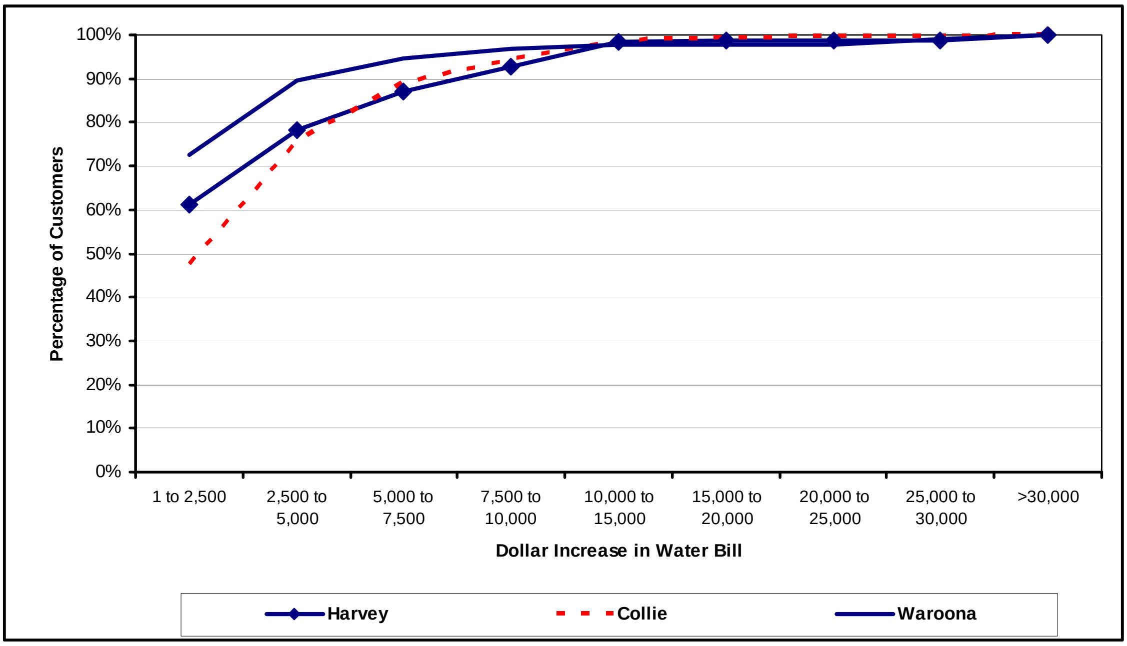


Chart 9.5: Customer Impacts - Percentage Increase in Water Bills Assuming 75% of Cost Allocated to Irrigators

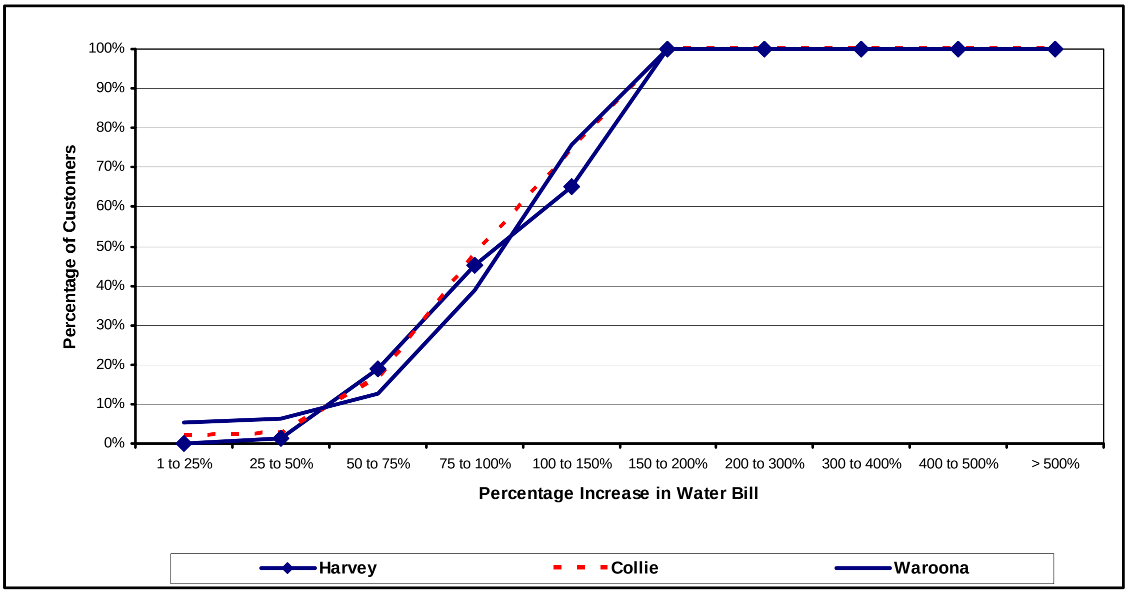


Chart 9.6: Customer Impacts - Dollar Increase in Water Bills Assuming 75% of Cost Allocated to Irrigators

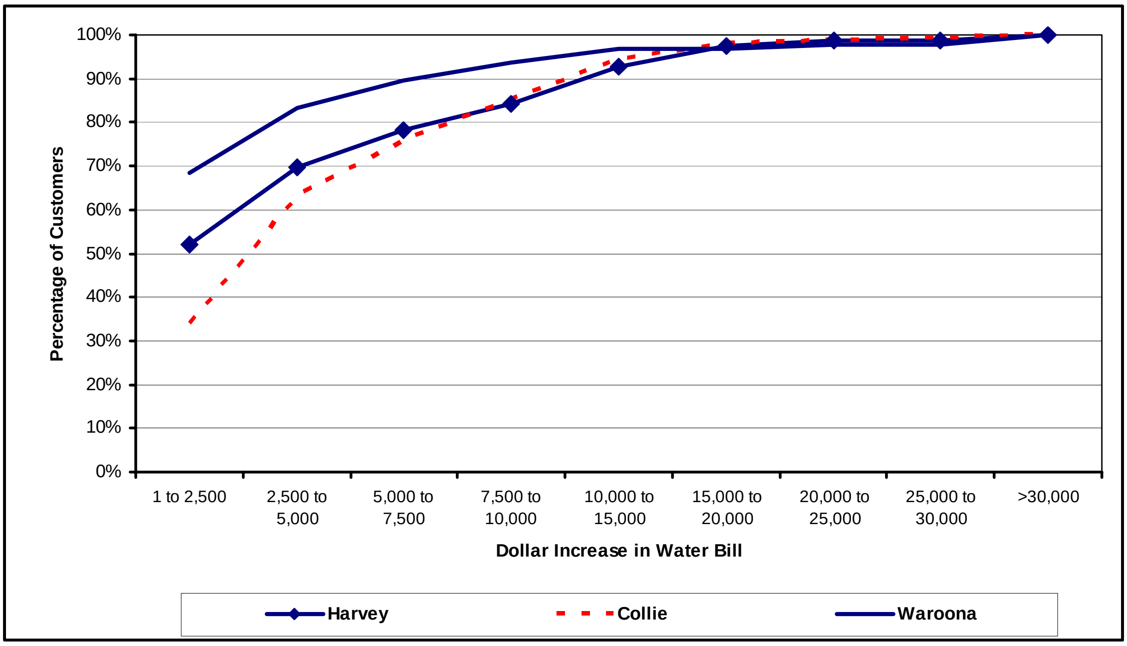


Chart 9.7 : Summary Statistics from Customer Impact Analysis

Statistic	**Cost Sharing Scenario**					
	25% Recovery		**50% Recovery**		**75% Recovery**	
	%	**$**	**%**	**$**	**%**	**$**
Median	36	939	72	1,878	107	2,817
Mean	40	1,621	79	3,243	119	4,864
Maximum Increase	62	52,623	124	105,246	186	157,869

- at 25% of the relevant costs allocated to irrigators, around 80% of irrigators would incur an increase in their water bill of less than 50% with a median increase of around 36%. However, for at leat 90% of irrigators, the dollar increase in bills would be less than $4,000 with a median increase of less than $1,000 and an average increase of around $1,600;
- at 50% of relevant costs allocated to irrigators, 60% of irrigators would incur increases in water bills greater than 50% with the median increase being around 72%. For 90% of irrigators in Harvey and Collie the dollar impact would be less than $7,500 and less than $4,000 in Waroona. The median increase would be around $1,900 within an average increase of around $3,250;
- at 75% of relevant costs allocated to irrigators, 70% of growers would incur percentage increases in water bills of at least 75% with 40% incurring increases greater than 100%, with a median increase of around 107%. For around 90% of irrigators in Harvey and Waroona, the dollar increase would be less than $10,000 and less than around $6,500 for Waroona irrigators. The median increase would be around $2,800 with an average increase of around $4,900;
- the largest percentage increase in water bills will fall on those irrigators that have entitlements but little or no usage as it has been assumed that the cost of dam safety would be imposed as a charge against entitlement, i.e., a fixed charge per ML of entitlement; and
- conversely, the largest dollar impacts will fall on those irrigators with the largest entitlements which generally are also those with the highest usage.

9.8 APPORTIONING OF COSTS OF DAM SAFETY WORKS BETWEEN BENEFICIARIES

9.8.1 FINDINGS & SOLUTIONS

Our prime findings and conclusions on these matters include:

- the **impactor pays and beneficiary pays** principles provide an initial base for discussing the apportionment of costs but must be supplemented by economic criteria, including demand and supply efficiency, equity and, importantly, affordability;
- **recognition of other beneficiaries** including consumptive use by the towns, recreational use by water-skiers, fishermen and others, and beneficiaries of reduced risk of dam failure such as the electricity and gas utilities, the rail and road system, residential and transient populations, and the environment and others. While irrigators are not typically located beneath the dams themselves, irrigators also benefit from increased safety since, in the event of failure, they would be unable to irrigate and likely lose production.
- **cost-sharing interstate** appears to charge irrigators somewhere between 12.5% and possibly up to 60% of total costs, with NSW and Victoria charging at a maximum 37.5% for MDBC dam safety upgrades and around 50% for their own dams.

  NSW and Victorian cost share ratios are based on small cost increases where a doubling of the price of water is seen as a matter of concern. *Prima facie* , the five to eight-fold price increases in bulk water prices in the South West suggest much greater issues of affordability and possibly lower shares for irrigators than 50%;
- the **legacy cost issues** have been explored extensively and endorsed by IPART. The concept of legacy cost is directly dependent on the adoption of the convention of "*a line in the sand*". Our discussions with IPART confirm that where a pre-existing agreement covers the same issues, the regulator cannot apply this convention unless the pre-existing agreement (in this case the BWSA) should be set aside.

  As a result, we conclude that the logic of the legacy cost issues cannot be directly applied in the case of the South West. However, IPART's extensive discussion highlights the strong support for the wider community paying a significant part of the cost of dam safety upgrades;
- **affordability** is a particular issue for dairy farming since milk prices have fallen substantially as a result of de-regulation. Farm performance survey results based on better farms indicate that at prices of 25-30 cents per L increases in water prices will have a significant effect on remaining profit. On the other hand, dairying in the South West is based on irrigated forage and supplementary feeding – rather than being wholly dependent upon irrigated pasture – and there is potential to move to more intensive dryland dairy farming;

Nonetheless, the affordability of dam safety expenditures is a much more critical and dominating issue in the South West (particularly in the Wellington catchment) than in the major irrigation areas elsewhere in Australia. In large part this stems from the comparatively very small yields from the dams, especially when compared with the bulk of Australian irrigators who are located in the southern Murray-Darling Basin. In response to the possible doubling of bulk water prices and associated capital constraints, Goulburn-Murray Water formally announced that its program will take 15 years to implement and we understand that this in fact may be longer due to demands for other capital expenditures;

- the convention "***as if they owned the dams***" is a useful assumption because it provides a strong alternative perspective on how the Waroona Dam Safety Program might have developed. As noted above, we consider that the example and lessons from Goulburn-Murray Water illustrate the approach that would likely have been followed had the dams been owned by Harvey Water, or alternatively if Harvey Water had been appropriately involved in consultation and deliberation as a major stakeholder. Experience in Goulburn-Murray and elsewhere indicates that the program would likely have proceeded on the basis of behaving prudently in accord with relevant standards, but spending as little as possible, as slowly as possible, and likely spending it rather differently; and
- strategic consideration of dam safety, storage and supply issues may have led to different choices and outcomes. The very small yield of Waroona Dam and the exceptionally high cost raises the immediate question of rationalisation and value for money – at least from the viewpoint of South West irrigators. For instance, would it have been better to have decommissioned Waroona and spent the balance on remedying the salinity problems of the Wellington catchment, which currently produces very poor quality water for both towns and irrigation?

  The focus on dam safety in isolation and the lack of consultation and stakeholder involvement for Waroona has arguably led to missed opportunities and higher resource costs for the Western Australian community.

9.9 MATTERS OF JUDGEMENT

The multiple considerations listed above as influencing the share that irrigators should be asked to pay need to be carefully weighed and a judgement reached. Having considered the issues, our thinking and judgement is that:

- First, cost sharing should be based on efficient and necessary costs including test timing and sequence.[72] As outlined, we consider that for Waroona, as distinct from all other dams where new procedures will be followed, there is a justifiable doubt that all costs were fully efficient and necessary, at least in the timeframe now in place. We therefore consider that a distinction should be drawn between Waroona and the remaining South West Dams.

[72] As indicated in Chapter 8, there is an obvious question as from whose perspective should efficiency and necessity be defined. We simple note that Water Corporation is not the only stakeholder involved.

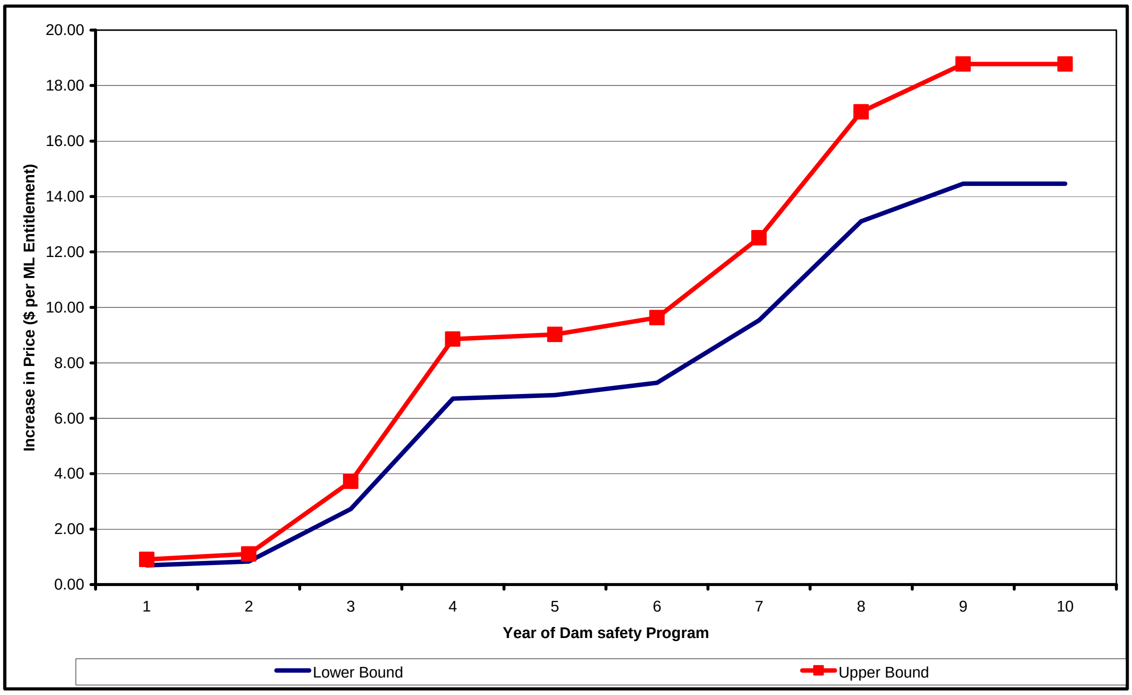
- Second, other beneficiaries must be recognised. These include consumptive use by the towns, recreational users of the dams and the beneficiaries of increased safety, i.e., the utilities, the transport system, the towns, the resident and transient population, and the environment.
- Third, as a matter of equity and precedent, we note that irrigators in the east (who have faced much smaller cost increases due to dam safety) have generally been asked to pay 50% or less of total costs. In Goulburn-Murray Water, the cost of increases at 100% share for irrigators is around $5/ML compared with an estimated $57/ML for the South West. This suggests that the South West irrigators should be required to pay no more than 50% of the relevant costs.
- Fourth, combining all factors we consider that the irrigators should be required to pay shares of 25-35% in respect of the now committed Waroona dam safety project and 40-50% in respect of the future program which will be developed under different processes and procedures.
- Fifth, we note the considerable uncertainty relating to the actual level of costs in the future program. The rise in the costs of the program from a notional $20 million indicated in the pre-privatisation discussion to now more than $100 million, plus or minus 50%, indicates the risk to irrigators and the State budget. We suggest that irrigators should be offered the choice of capping this risk.

The eleven-year period over which the dam safety upgrade program will now be undertaken ensures that irrigators are provided with a period over which to plan for, and adjust to, increased prices (refer Chart 9.8).

The cost-sharing judgement provides appropriate financial incentives for all three parties involved:

- First, the comparatively high cost to irrigators provides Harvey Water with a strong commercial imperative to maintain a close watching brief on future dam safety upgrade solutions and its role from a strategic water resource management perspective. Moreover, it should ensure that Harvey Water maintains close scrutiny throughout the scoping, planning and implementation phases.
- Second, the cost to the public purse should ensure that the Western Australian Treasury adopts a more active role in the area of dam safety decision-making and funding. It should provide greater scrutiny of the *prima facie* differential in dam safety standards vis-à-vis other areas of public safety and, therefore, the allocation of scarce community resources between the different areas of public risk.

Chart 9.8 : Impact on the Average Annual Price to Irrigators of the Recommended Bounds for Cost Sharing



- Third, the cost-sharing and related institutional funding arrangements should help ensure that Water Corporation examines dam safety in the South West from a total water resource management context and that the developed solutions are clearly least cost and have been thoroughly scrutinised by both the major customer and the State Treasury.

Desirably, these incentives and the findings of this report should assist Harvey Water and Water Corporation developing strategies that maximise the economic benefit derived from water resources in the South West of Western Australia.

9.10 NEXT STEPS

This report and its recommendations will require consideration and action by all the major parties, that is, the State Government, Water Corporation and Harvey Water.

For the State Government, the report has raised the major issue of how the total portfolio of risks facing the State Government, its agencies and Treasury should be managed. An immediate and particular issue is how capital expenditure should be prioritised. The State Treasurer has already indicated increasing attention to this issue.

The State will also review these findings and conclusions in the context of the State Water Strategy and the Irrigation Review.

For Water Corporation, the report has indicated several areas where the strong process already in place can be improved. A particular challenge will be to prioritise dam safety and other capital expenditures against the tightening constraint of capital.

For Harvey Water, the implementation of large cost imposts across its irrigator members is a key challenge which will force it to consider its longer term vision and strategies. The Irrigation Review and other challenges indicating the specification of its bulk licence and response to the increasing scarcity of water resources in the South West of the State are important and immediate challenges.

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ATTACHMENT
TECHNICAL REPORTS

Appendix A
Detailed Comments on Hydrological Issues

A.1 General

The following sections provide the technical detail used to formulate the summary comments provided in the main body of the report. The order of the sections loosely follows that adopted by the hydrology reports.

A.2 Design Rainfall Inputs

A.2.1 General

Information on the depth of rainfalls is a primary input to the models used to estimate the design floods on interest. The attributes of the rainfalls that merit comment include:

- short duration (6 hours and less) seasonal PMP rainfalls;
- longer duration seasonal PMP rainfalls;
- distribution of rainfalls between 1 in 100 events and the PMP;
- spatial and temporal patterns of rainfalls; and,
- antecedent rainfalls.

These are discussed in the following sections.

A.2.2 Short duration events

Seasonal short duration rainfalls for Probable Maximum Precipitation (PMP) events have been derived from information provided by the Bureau of Meteorology. The reports do not present information on the seasonality of short duration PMP events, though it is assumed that the procedures outlined in Bulletin 53 (Bureau of Meteorology, 1994) have been used.

No information has been provided on how the seasonality of short duration rainfalls varies with smaller magnitude events (ie on the seasonality of short duration rainfalls up to the 1 in 100 AEP event), though such information has been derived for longer duration events (e.g. greater than 24 hours, see Pearce, 1998). It would be important to incorporate the seasonality of these short, more frequent rainfall events to aid calibration and verification of model parameters. The seasonality of short duration events was investigated as part of this review to help evaluate the importance of considering seasons of different duration (see Section A.3). The results obtained for six hour events are shown in Figure A-1, and the seasonality exhibited by this data is similar to that documented by Pearce (1998) for longer duration events. It would be desirable to further investigate the seasonality of these short duration events (for the limited amount of data that would be available) for a larger group of sites. The analysis of the seasonality of short duration events would be of particular relevance to the calibration and verification of loss model parameters, as discussed in Section A.4.

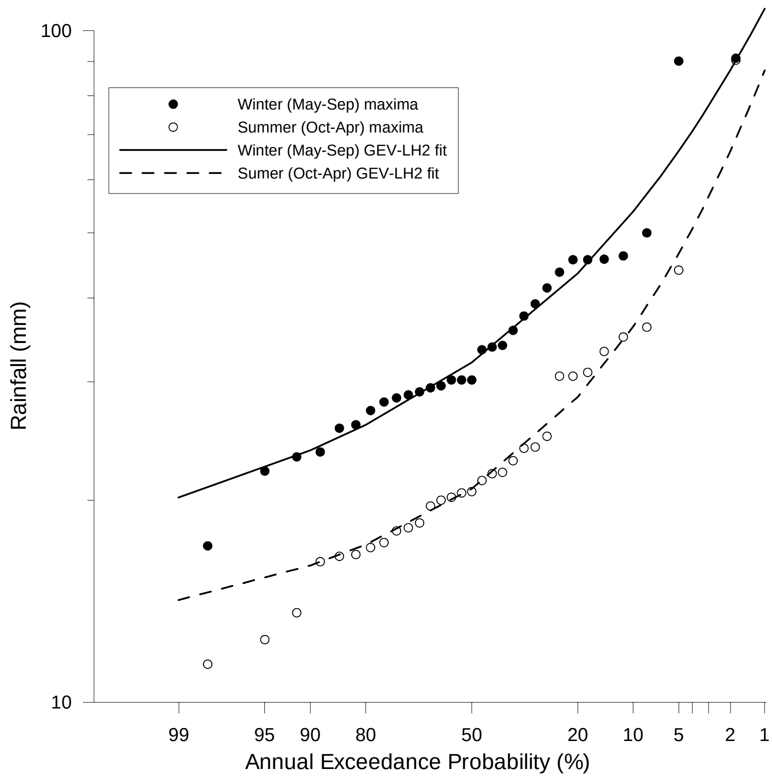

FIGURE A-1 SEASONALITY OF SHORT DURATION RAINFALL EVENTS (ANNUAL MAXIMA OBTAINED FROM PERTH REGIONAL OFFICE, AND ARE FITTED TO THE GENERALISED EXTREME VALUE DISTRIBUTION BY LH-MOMENTS)

Long duration events

The Bureau of Meteorology have recently revised the manner in which longer duration PMP events (over around 12 hours duration) are estimated. This revision incorporates a number of advantages, namely:

- more accurate estimates of the PMP depths;
- a defensible approach to the seasonal distribution of extreme rainfalls; and,
- a sample of temporal patterns (which distribute rainfall depths over the duration of the burst being considered) rather than a single, fixed pattern;

The studies completed to date have all been based on the earlier information provided by the Bureau of Meteorology, and thus for future studies it will be necessary to update this work to capture the improved understanding of extreme rainfalls. It is understood that the Water Corporation has already embarked on the incorporation of this revised design information.

Intermediate Probabilistic Events

It is also understood that the WA Water Corporation has decided to embark on the derivation of rare (long duration) rainfalls with exceedance probabilities of around 1 in 2000 AEP using CRC-FORGE procedures. This range of probabilistic rainfalls is particularly relevant to assessing the need for upgrading dams from their current configuration. However, it should be noted that this information may not be as relevant to the south-west portfolio of dams due to their small catchment areas (this excludes Wellington Dam, and those dams such as Logue Brook for which it is found that initial reservoir level is important).

While it would be tempting to assume that the distribution of longer duration events could be applied to shorter duration events, without appropriate evidence or research such an assumption would be difficult to justify. With respect to the portfolio of south-west dams it would thus be of considerable advantage to investigate whether the limited amount of rainfall data (compared to that available for the longer duration events) can be incorporated in the proposed CRC-FORGE analysis, either by application of the CRC-FORGE technique directly or else by investigation of functional relationships developed from short duration events.

Temporal and Spatial Patterns of Rainfall

To date the studies have adopted fixed spatial and temporal patterns of rainfalls (for distribution spatially across the catchment, and over the duration of the design event). This is in accordance with accepted design practice.

As mentioned in Section 0, long duration storms provided by the Bureau of Meteorology are now provided with a sample of temporal patterns. Use of these individual patterns – both selectively and stochastically – will yield more accurate and robust results than compared to the adoption of a single, fixed pattern. The problem for the majority of the south-west dams is that the patterns provided are only relevant to long duration events. However, further regional analysis could be undertaken to derive a corresponding set of short duration temporal patterns.

The approach taken with the spatial distribution of rainfalls could theoretically be improved upon, but given the size of the catchments and the absence of design precedents, there is little or no justification for doing so.

Antecedent Rainfalls

The rainfall information provided by the Bureau of Meteorology relate to the depths of rainfall over an *intense burst* of specified duration; they do not represent “real” storms. This distinction has required little consideration in the past, however the recent flood guidelines provide some discussion on the benefits of incorporating information on “pre-burst” rainfalls (that is the depth of rainfall that could be expected to occur in a “real” storm prior to the burst of highest intensity). It is considered that the incorporation of pre-burst rainfalls would obviate the need to alter initial moisture stores with event magnitude (see Section A.4), and thus would provide a better basis for extrapolation to extreme events.

While information is available in other parts of Australia on the likely magnitude of pre-burst rainfalls, nothing is at present available for rainfall events in the study region (for either short or long durations). Such information could be derived by undertaking an investigation of regional rainfalls. The outcomes of a single regional study would be applicable to all dams in the region, and would be expected to aid the parameterisation and representation of loss modelling for all dams of interest.

A.3 Seasonality

Currently most design flood estimates in Australia are determined on an annual basis. This means that flood data and other relevant design data are applied regardless of the season in which they were observed. In the south-west of Western Australia there is clear evidence (e.g. Pearce, 1998) that rainfall maxima are markedly seasonal, and that the nature of this seasonality varies with the magnitude of the event. Thus, for more frequent events (say for events with an AEP of 1 in 5) the rainfall maxima are more likely to occur in the winter period; as the severity of the event increases (say up to 1 in 100 AEP) the maximum could perhaps occur equally likely in either winter or summer. However, for extreme events, such as those associated with short duration Probable Maximum Precipitation (Bureau of Meteorology, 1994), it is highly likely that the event will only occur in the summer season (ie, October to April, inclusive).

The seasonality of rainfall occurrence is recognised in the hydrology reports. The seasonality of the longer duration rainfall events (over around 12 hours duration) used in the hydrology reports should be regarded as being only weakly defensible, though the information being currently provided by the Bureau of Meteorology (2002) does rectify this issue. This is only of relevance to Wellington and Stirling Dams, as the critical durations for the other dams are mainly a function of short duration events (around six hours durations).

Rainfall is not the only flood producing mechanism that varies seasonally. Other potentially important factors include infiltration losses, likely initial reservoir level, and baseflow. While these other factors vary seasonally, they are out of phase with the distribution of rainfall. This concept is schematically illustrated in Figure A-2, where it may be seen that the peaks and troughs of the rainfall period do not coincide with the seasonality of the other factors. Thus, for example, the maximum rainfall period occurs over summer period when infiltration losses (associated with low soil moisture conditions) are likely to be high.

The hydrology studies have all been analysed assuming two seasons (indicated as “summer” and “winter” in Figure A-2). This involves the assumption that specific combinations of these factors are likely to occur together, or at least that the selected combination is typical of the range of combinations that are likely to occur within each specified season. Given the significant variation of the factors between flood events, it is often necessary in practice to focus the analysis on some dominant combinations and neglect those combinations that are unlikely to contribute significantly to the total flood probability. However, as illustrated in Figure A-2, it appears reasonably possible that if only two seasons are selected then unlikely combinations of factors may result. For example, with the specified seasonality, high rainfalls could occur with either high or low losses, and in terms of outflows, these may coincide with either low or high initial reservoir conditions.

In order to better represent these seasonal factors by representative average (or distributional) values, it may be more appropriate to divide the year into four seasons. The likelihood of rainfall depths of a given magnitude may be differentiated across only two seasons, but the other factors could be varied as deemed appropriate.

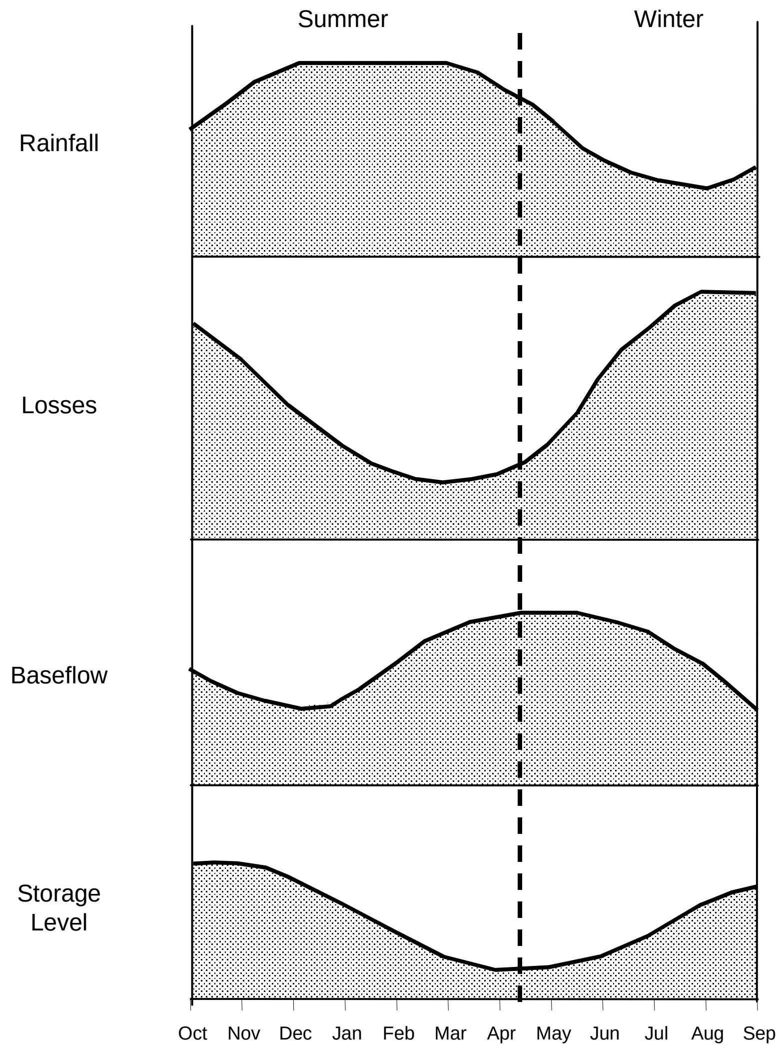

FIGURE A-2 SCHEMATIC ILLUSTRATION OF THE SEASONALITY OF FLOOD MODIFYING FACTORS

In order to investigate the impact of a different number of seasons on the results, Monte-Carlo simulation (Nathan et al, 2002) was used to derive inflow and outflow frequency curves. The manner in which the initial loss store was sampled is discussed in

Section A.4. The simulations were based on the Logue Brook catchment, though the results should be viewed as being notionally indicative of the sensitivity to seasonality as the version of loss model used has not been calibrated. Results were obtained for the 6-hour event for inflows, and a 24-hour event for outflows, and the results are summarised in Figure A-3.

It is seen that adoption of two rather than four seasons may lead to underestimation of the magnitude of the flood peaks by around 10% to 20%. In terms of the likelihood of overtopping, if it is assumed that the likelihood of overtopping the dam crest for two seasons is around 1 in 5000 AEP, then adoption of four seasons results in a five-fold increase in overtopping likelihood (around 1 in 1000 AEP). Clearly the difference between the results lessens as the magnitude of the flood events increase.

If the inflow design floods are adequately calibrated (ie it is assumed that the both methods are calibrated to yield the same estimate of, say, the 1 in 100 AEP event), then incorporation of four seasons for losses will have little influence on the magnitude of the inflow floods. This is because the slope of both curves are the same, and they will be anchored at the same point. Accordingly, the increase in overtopping likelihood by sampling from four seasons will perhaps be less (say between a three- to four-fold increase).

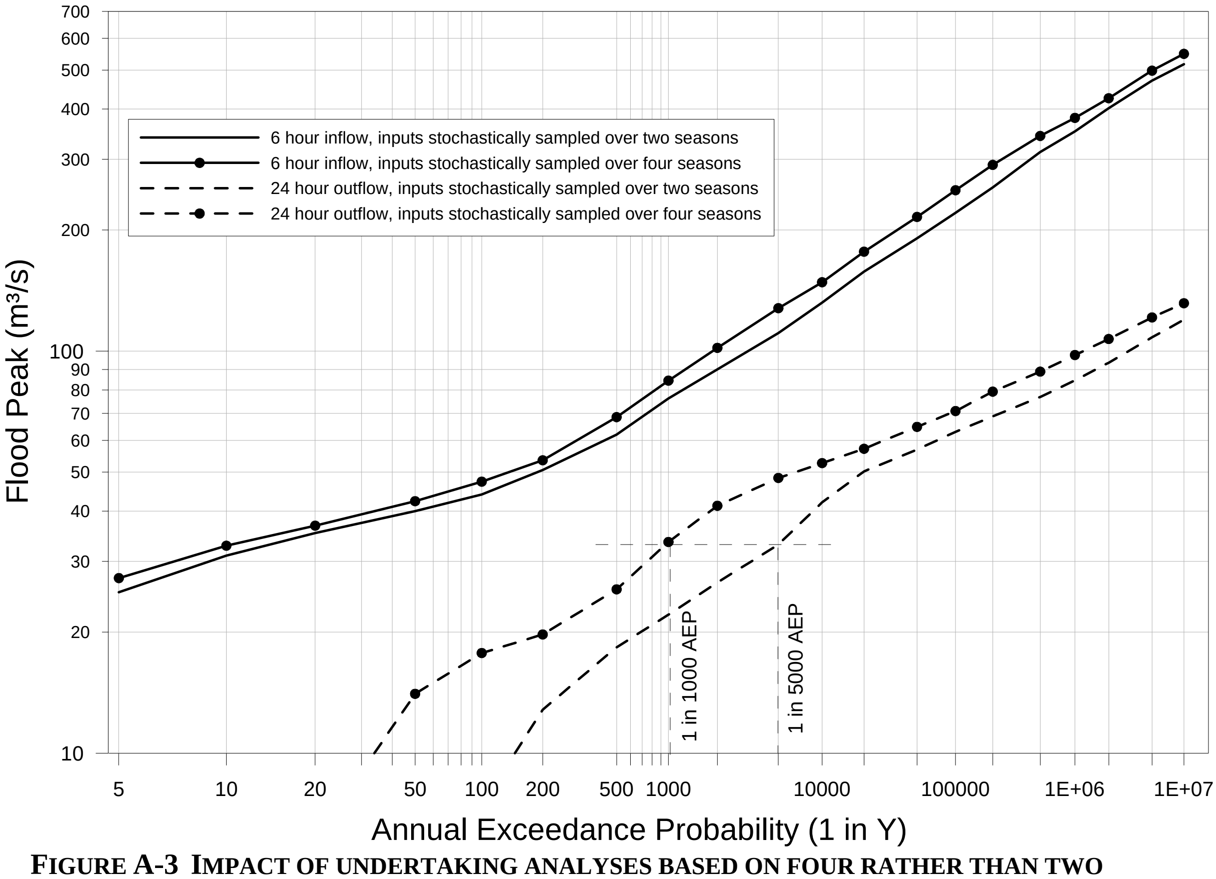

FIGURE A-3 IMPACT OF UNDERTAKING ANALYSES BASED ON FOUR RATHER THAN TWO SEASONS (LOSSES, INITIAL STORAGE LEVEL, AND TEMPORAL PATTERNS ARE STOCHASTICALLY SAMPLED).

A.4 Rainfall Losses

A.4.1 General

Losses associated with extreme rainfall events are generally assumed to be low or zero in many parts of Australia. In addition, it is common to assume that loss rates are constant throughout the duration of the rainfall event.

By contrast, the loss values assumed for the south-west catchments are far higher than used elsewhere in Australia, and they are allowed to vary over the duration of the event. The losses are estimated using a conceptual model developed by Stokes (1989), the details of which are described in an unpublished report (by the Water Authority of Western Australia). Although the conceptual basis of the loss modelling used is appreciably different to that used elsewhere in Australia, it appears to be well founded on empirical evidence and appropriate to the unique characteristics of the region. The use of field data to derive the soil water storage characteristics and their spatial variation for different landform classes, also seems to be a strength of the adopted approach.

The issues concerning the manner in which losses are modelled can be divided into three areas, namely: model conceptualisation, AEP-neutrality, and parameter identification. These three issues are discussed in the following sections.

A.4.2 Model conceptualisation

Overall the conceptual basis of the loss model appears well founded and attractively linked to empirical evidence. The use of such a model in this region is strongly endorsed. However, while the conceptual basis of the model itself is defensible, the manner in which it is fitted to historic events and then used in design presents some difficulties.

The main concepts underlying this issue are illustrated in Figure A-4. For historic events the proportion of the catchment that is contributing directly to runoff is a function of initial soil moisture conditions. At present it is assumed that these initial conditions exist for both “small” and “large” floods, which thus implies that the initial proportion of the catchment contributing to runoff is the same regardless of the magnitude of the flood being considered. While the assumption of similar initial soil moisture conditions may be valid prior to rainfall *storms*, it is less likely to be valid prior to rainfall *bursts* because (for a fixed proportion of antecedent rainfalls) more rainfall will occur immediately prior to a large burst than to a small one. (Further discussion on the implications of fitting the model to historic storms and then using it with design bursts to estimate floods is provided in Section A.4.4). This issue could be addressed by either increasing initial soil moisture conditions with increasing flood magnitude, or else by incorporating information on pre-burst rainfalls and keeping initial soil moisture conditions fixed. The latter approach is considered more attractive as the necessary information required to vary initial conditions with event magnitude would be difficult (if not impossible) to quantify for this region.

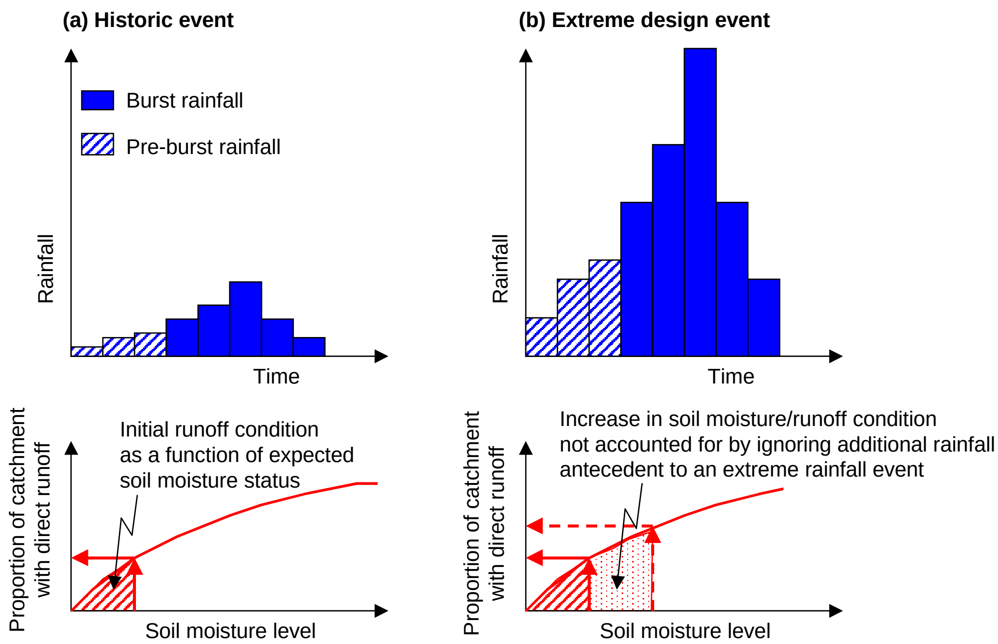

FIGURE A-4. SCHEMATIC ILLUSTRATION OF THE IMPACT OF PRE-BURST RAINFALLS ON LIKELY INITIAL RUNOFF CONDITIONS FOR (A) TYPICAL HISTORIC EVENTS, AND (B) EXTREME DESIGN CONDITIONS.

The results of some exploratory analysis of incorporating pre-burst rainfalls are illustrated in Figure A-5. These results were obtained by setting the initial moisture store to a fixed value, and assuming that the pre-burst component was 15% of the burst depth. It is seen that the two sets of results for the inflow are approximately parallel (in the log-Normal domain), such that at lower magnitudes the differences are around 25%, but at higher magnitudes the differences increase to around 50%. It would be hoped that with adequate calibration it would be possible to “anchor” the curves at, say, the 1 in 50 AEP event, in which case any remaining practical differences between the two sets of curves may be of little consequence. Discussion on improvements to the calibration procedure are discussed in Section A.4.4.

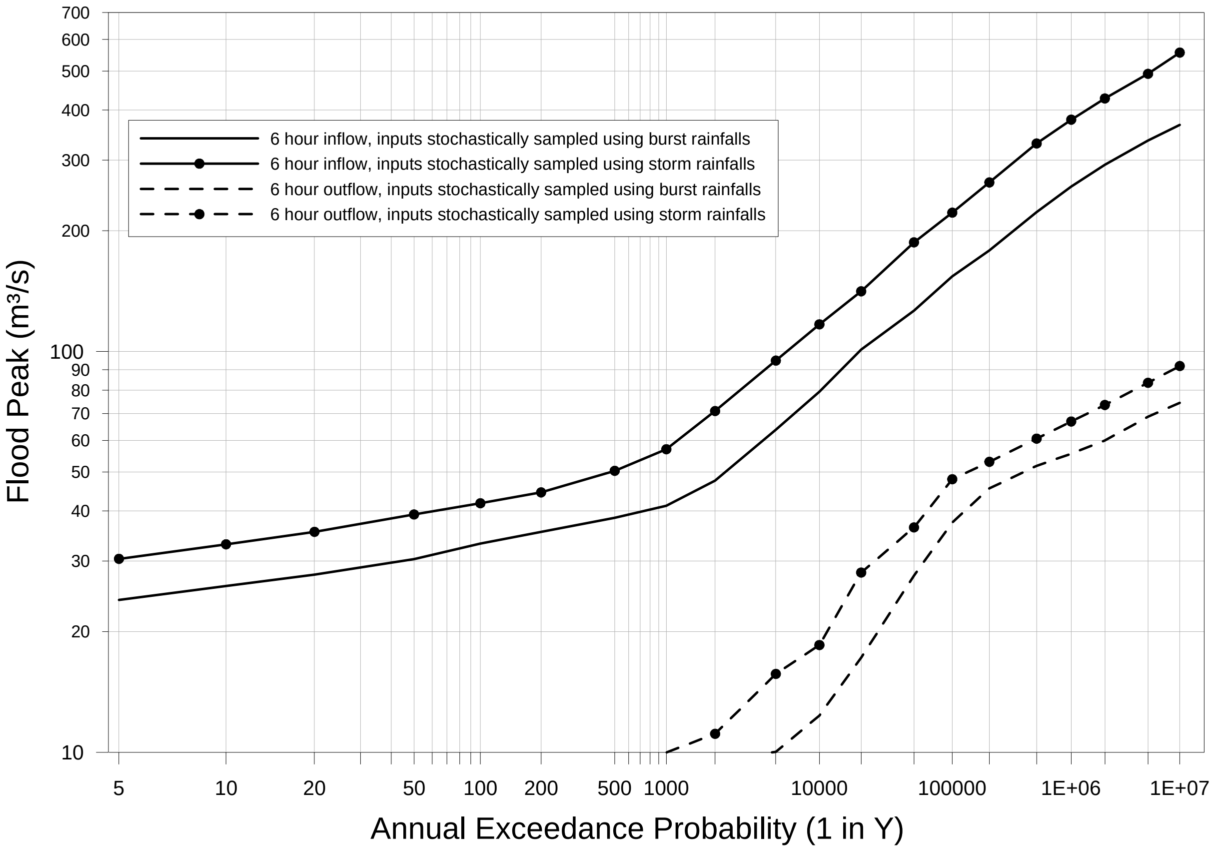

FIGURE A-5 IMPACT OF TAKING INTO ACCOUNT THE INFLUENCE OF PRE-BURST RAINFALLS ON LOSS MODELLING.

A.4.3 AEP-Neutrality

At present the loss modelling is undertaken assuming that the initial seasonal storage condition is fixed for all durations and for all magnitude of events. If design storms are used instead of design bursts, then there should be no need to account for differences in event duration. With respect to the magnitude of the event, the appropriateness of using a single fixed value is dependent on how linear the relationship is between initial loss and peak runoff. Certainly over the range of rainfalls of interest the relationship between initial model store, rainfall excess, and rainfall depth is non-linear, and thus it would be expected that the adoption of a fixed initial store introduces some bias, that is, the transformation between rainfall and flood peak does not preserve AEP-neutrality.

In order to investigate this issue it is necessary to have some understanding of the distribution of soil moisture conditions in the catchment. Such information is best obtained by empirical means (e.g. Hill et al., 1996), though it is possible that simulation techniques could be used as a surrogate. The latter approach was adopted to investigate the likely sensitivity of the results to adoption of a fixed value rather than a distribution of values.

For the purposes of this review a simulation model was developed based on the SWMOD model developed by Stokes (1989). A schematic of the developed model is shown in Figure A-5. It is a very simple model and in practice it would be desirable to model a baseflow store and calibrate against a streamflow series, however it is considered suitable for the purposes of investigating sensitivity to soil moisture conditions. The model was run using a daily sequence of rainfall data collected at Harvey Post Office (009554) over the period 1950 to 1991. For each day, daily rainfall was partitioned into surface runoff and accession to soil moisture using the SWMOD function. Evaporation from the soil store was achieved using a simple function in which for wet conditions the evaporative loss was equal to the potential rate, though this rate was progressively decreased as soil moisture levels decreased. Information on potential evaporation was taken from the Bureau of Meteorology maps of areal potential evapotranspiration, as described by Francis et al. (2001).

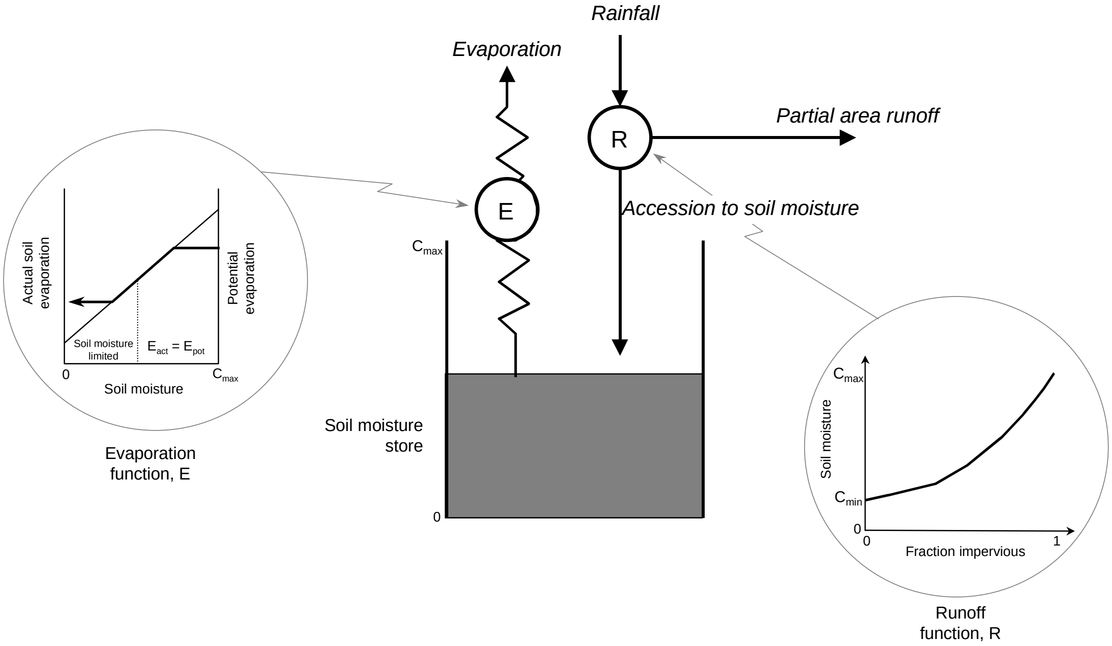

FIGURE A-5: SCHEMATIC OF SWMOD CONTINUOUS SIMULATION MODEL.

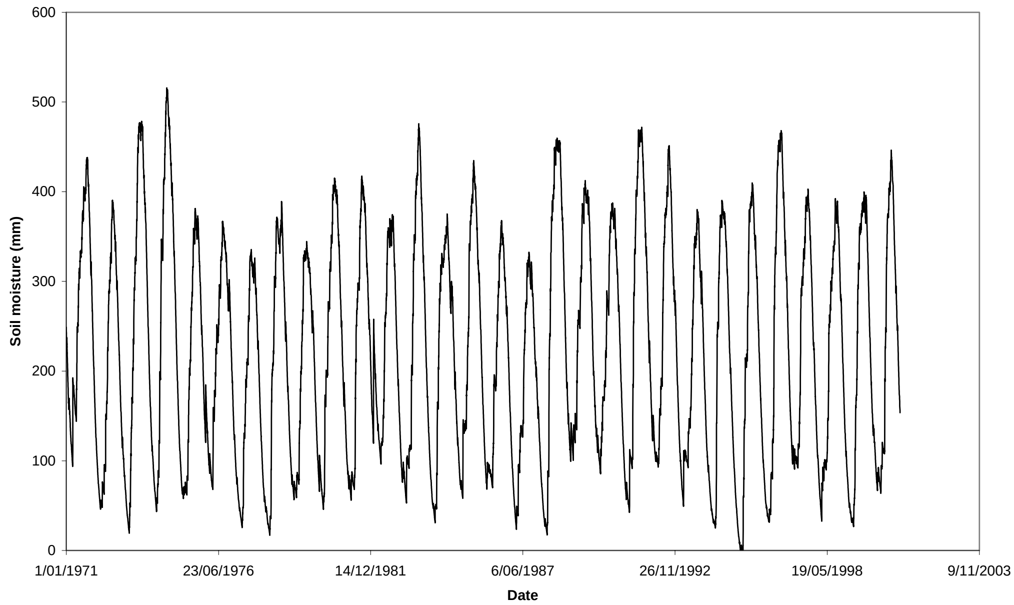

FIGURE A-6: TIME SERIES OF SYNTHETIC SOIL MOISTURE LEVELS OBTAINED FROM SWMOD CONTINUOUS SIMULATION MODEL.

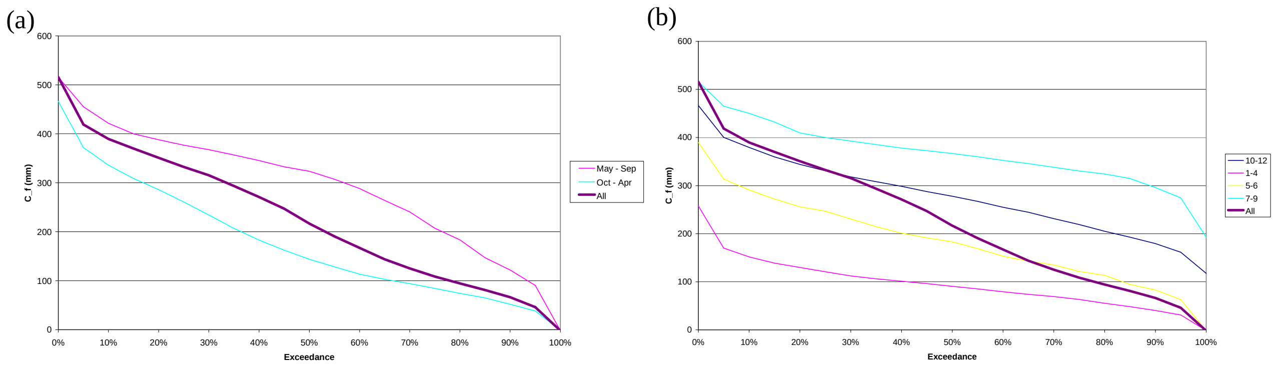

FIGURE A-7. ANNUAL AND SEASONAL CUMULATIVE FREQUENCY DISTRIBUTIONS OF SOIL MOISTURE BASED ON (A) TWO SEASONS AND (B) FOUR SEASONS.

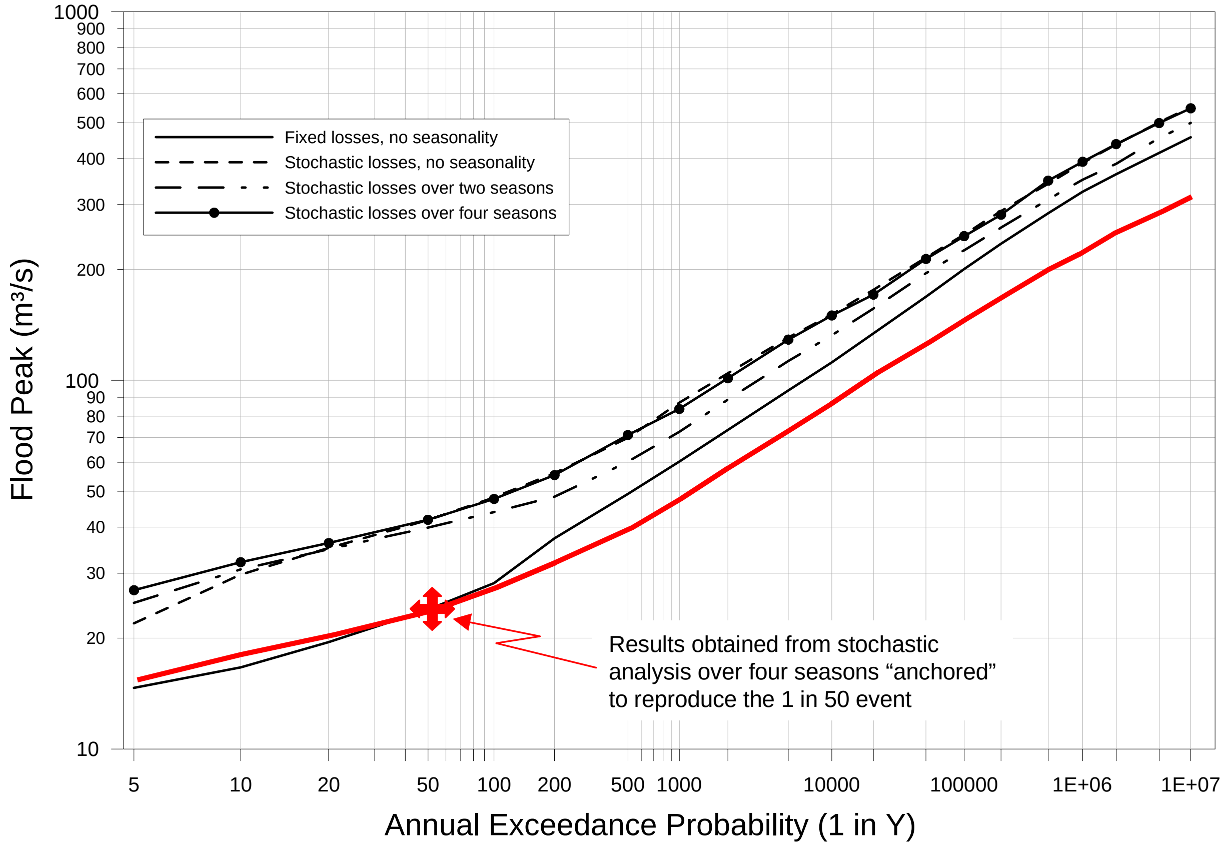

FIGURE A-8 IMPACT OF TAKING INTO ACCOUNT THE DISTRIBUTION OF INITIAL LOSS PARAMETERS COMPARED TO FIXED SEASONAL VALUES (TWO SEASONS ARE BASED ON OCT-APR AND APR-SEP, AND FOUR SEASONS ARE BASED ON MAY-JUN, JUL-SEP, OCT-DEC, AND JAN-APR).

A plot of soil moisture conditions concurrent with the rainfall series is shown in Figure A-6. From this series a non-parametric distribution of soil-moisture conditions was obtained for annual, two-seasonal, and four-seasonal periods. The cumulative frequency curves of the soil moisture conditions is shown in Figure A-7.

The sensitivity of the results to adoption of a fixed versus a seasonal distribution of initial soil moisture conditions is shown in Figure A-8. The results were obtained using Monte-Carlo simulation techniques, in which the initial soil moisture was sampled from the different distributions. For consistency, the results for the fixed initial soil moisture conditions were obtained by adopting the median soil moisture level derived from the different distributions. A simplified version of SWMOD was incorporated into the Monte-Carlo framework, in which only one soil type was represented and the gross rainfall was assumed to be spatially uniform across the catchment (the Dwellingup soil parameters were used where C_{max}, C_{min}, and b were set to 1440, 96, and 2.25, respectively).

It is seen that the adoption of a distribution of initial soil moisture conditions yields quite different results to that obtained using a fixed value, even if seasonality is neglected. It appears that taking account of variability in soil moisture conditions yields higher peak flows than for fixed initial conditions, particularly for the more frequent events. If it is assumed that the model is calibrated correctly (thus the estimates of, say, the 1 in 50 AEP event are the same for both approaches) then it is evident that adoption of a distribution of values yields *lower* extreme flood estimates than the current approach. This is illustrated by the thick red (annotated) line in Figure A-8. The difference increases as the magnitude of the event increases; for example for inflow events around the 1 in 5000 AEP event the distributional approach would yield results around 25% lower, for the PMPDF the results would be around 35% lower.

A.4.4 Calibration of Model Parameters

The foregoing sections highlight some of the conceptual and practical difficulties of the adopted approach. Currently the parameters of the loss model are determined by fitting to a small number of historic events. These events represent “whole” storms, that is observed rainfall events with a specified beginning and end, and a concurrent streamflow hydrograph. It is likely that the annual exceedance probability of these calibration events ranges between 1 in 2 to around 1 in 20. Once model parameters have been fitted to these events the model is used directly to estimate design floods with annual exceedance probabilities ranging between 1 in 100 and 1 in 10^7.

There are two potential problems with this approach. Firstly, the design floods are derived from design bursts of rainfall, not complete storms. That is, rather than using rainfall events that may (or may not) have preceding (and subsequent) periods of lower rainfall intensity, the design rainfalls are comprised solely of an intense burst of rainfall of a specified duration. The characteristics of these design rainfalls may be (in fact usually are) quite dissimilar from real observed rainfall storms, their main characteristic of interest is the depth of rainfall that falls within a specified period. The physical basis of the loss model – indeed its very parameterisation – is compromised by the fact that it is fitted to complete storms yet applied to storm bursts. This difference in rainfall characteristics is likely to result in a systematic *underestimation* of peak flows. One potential compensation is that the model is selectively fitted to the largest observed floods where it may be assumed that antecedent conditions are unusually wet – the deliberate bias introduced in the sample used to calibrate the model is likely to result in a systematic *overestimation* of peak flows.

The adopted approach thus implicitly assumes that these two systematic biases fully compensate one another. While this may be the case, there is no evidence provided in any of the reports that addresses this issue. This lack of defensibility (arising from the difference between rainfalls used to calibrate the model and that used to estimate the design floods) is best rectified by comparing the design floods derived using the model with independent estimates obtained by another method. Independent estimates of design flood peaks can be obtained by a statistical analysis of observed flood maxima, though to do this with any confidence it is desirable to use long periods of historic data (say, more than 20 years). While it is recognised that such information is available only in a minority of cases, such an analysis lends itself easily to regionalisation and the results of a single study based on all available data would be applicable to all dams in the region. The manner in which the two independent sources of information can be used to help reconcile differences in the estimates is illustrated in Figure A-8.

Compared to the current reliance on a small number of historic events, adoption of this calibration approach would make better use of the seasonal rainfall and available flood frequency information, and is better suited to resolving the conceptual inconsistencies that arise between the use of "real world" data and statistically derived design inputs.

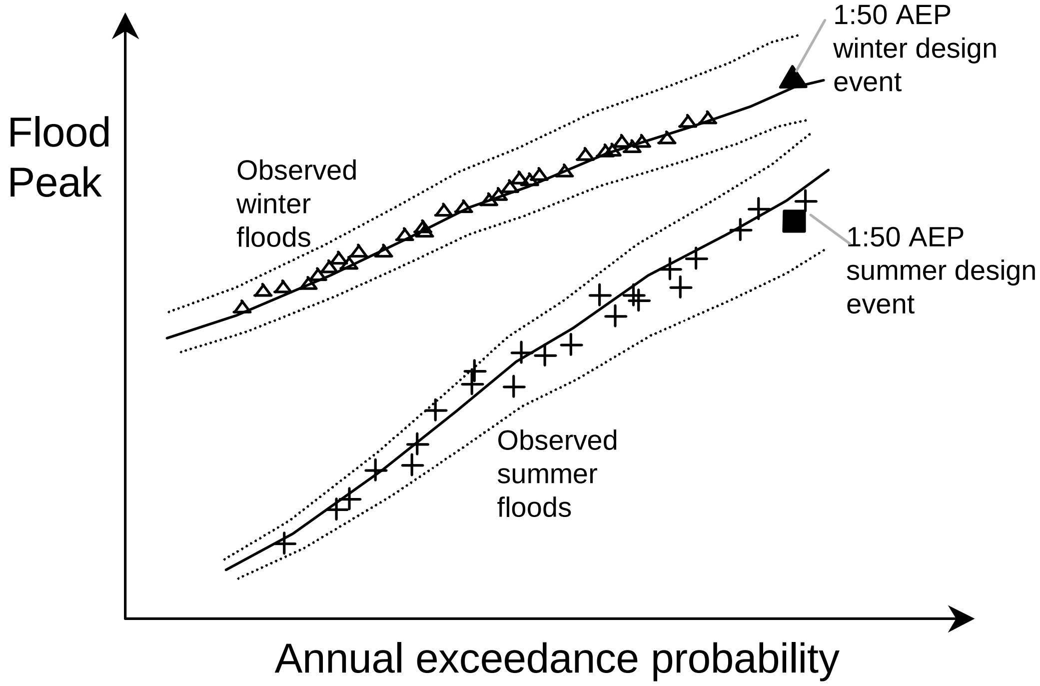

FIGURE A-9 SCHEMATIC ILLUSTRATION OF A METHOD THAT COULD BE USED TO HELP DEMONSTRATE EFFICACY OF LOSS MODEL WHEN USED TO DERIVE DESIGN FLOOD EVENTS.

A.5 Baseflow

The hydrograph model used only gives the direct storm runoff, and some baseflow must be added to obtain the total hydrograph. For most of Australia baseflow is small compared with direct runoff, especially for extreme floods, and in some regions it may be neglected. However, in the south west of Western Australia baseflow is an appreciable proportion of observed floods (e.g. Harvey, 1982) and thus it is appropriate to adopt higher values than generally used elsewhere.

The approach used in the most recent version of reports is to include baseflow as a fixed proportion of the flood peak. The proportion is assumed to vary with season, where it is assumed that in winter the contribution is around 30% and in summer it is 5%.

There are two components to baseflow that need to be considered. The first is the residual contribution from groundwater arising from previous rainfall events – this component is the result of past events and decreases over the duration of the flood event being simulated. The second component represents the delayed contribution of sub-surface flows associated with groundwater mounding – this component is the result of recharge from the current event and its magnitude is expected to vary in some (generally non-linear[73]) fashion.

The implication of the current approach is that groundwater discharge is linearly proportional to the peak of the event being simulated, and that the peak of the baseflow coincides with the peak of the surface runoff event. With respect to magnitude, this is possibly quite a simplistic assumption, and some justification for its adoption needs to be provided. With respect to timing, this is erroneous for it cannot be expected that the attenuated contribution of groundwater rises and falls at the same time as the surface runoff contribution. Since the most extreme events are dominated by summer storms, the likely impact of an alternative assumption on the PMP Design Flood[74] is likely to be small. However, since the magnitude of floods that cause overtopping of the dam are in general considerably smaller than the PMP Design Flood, it is possible that the adopted approach results in conservatively high estimates of overtopping likelihoods.

Lastly on this point, it appears that the groundwater contribution is input immediately upstream of the dam. If the groundwater contribution is as large as that indicated and is considered to be the result of the spatially distributed rainfalls, then it would be preferable for the groundwater to be input in a distributed fashion throughout the model. This allows for the groundwater to be combined with the surface water contribution prior to being routed through the channel stores. While theoretically desirable, the inclusion of baseflow does introduce other complications that need to be considered carefully (see Dyer et al. 1993).

Parameter Identification

It is noted that the size of the flood events used to calibrate the runoff-routing models are around 1/10th to 1/80th the magnitude of the final PMP Design floods. This is not unusual, and reinforces the need to use more than one calibration strategy.

In general, it is suggested that the historical flood events be used to calibrate the routing parameters of the RORB model. Where appropriate some reliance should be placed on the results obtained from previous studies, for example the results presented by Pearce and Ruprecht (2000) could be censored to determine expected variation in k_c with catchment area that is relevant to the region of interest. Refinement of the loss model parameters is best achieved by reconciliation of the differences between the rainfall-based estimates and flood frequency quantiles (as described in Section A.4.4).

[73] In phreatic groundwater systems (as characterised by the Boussinesq equation) groundwater discharge is linear with respect to the square of increases in groundwater level.

[74] The PMP Design Flood is the flood with the same annual likelihood of exceedance as the Probable Maximum Precipitation.

There does appear to be reasonable consistency between the results obtained for the different studies, as illustrated in Figure A-10. This degree of consistency would be expected if the catchments have similar landforms and are in a meteorologically homogeneous region. Similar plots as those shown in Figure A-10 could be developed based on flood quantiles fitted to observed flood maxima. This information would be of considerable use when deriving independent flood estimates in catchments with little or no gauging data.

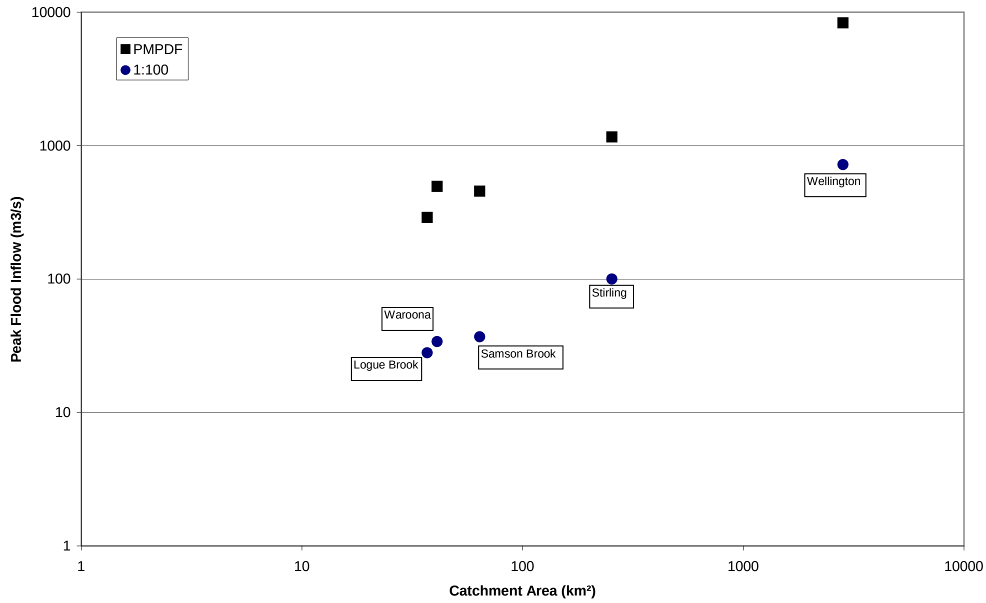

FIGURE A-10 DEGREE OF CONSISTENCY BETWEEN 1 IN 100 AND PMP DF RESULTS.

Initial Reservoir Level

In all studies it was assumed that the initial reservoir level was at full supply level prior to the onset of floods. The appropriateness of this assumption is dependent on two factors, namely: (i) the likelihood that the storage is below full supply level at different times of the year, and (ii) the volume of "air-space" in the reservoir compared to the volume of the inflow flood. No information is provided in the reports regarding the appropriateness of the initial full supply level assumption.

Some indication of the potential reductions in outflow that could be achieved is provided in Table A-1. In this table it is speculatively assumed that the top one third of the storage volume might be available to absorb the rising limb of the inflow hydrograph. (The validity of this assumption is unknown, though given that extreme events are almost certainly likely to occur in summer this is a considered a reasonable basis on which to illustrate the possible degree of importance). This volume of "air-space" is converted to a depth of runoff, which is represented as a proportion of the PMP rainfall depth and a proportion of the PMP DF volume. It is clear from this table that if there is any chance of Waroona and Stirling being drawn down then this could have a large impact on the estimated likelihood of overtopping failure.

TABLE A-1 NOTIONAL AVAILABLE AIR-SPACE REPRESENTED AS DEPTH OF FLOODING AND PROPORTION OF RAINFALL DEPTH AND RUNOFF VOLUME.

Dam	Full storage volume GL)	Volume of Air Space (assumed to be 1/3 full storage)		
		Depth of Runoff (mm)	Proportion of PMP DF volume (%)	Proportion of PMP (%)
Waroona*	14.9	18	5	3
Samson Brook	8	42	6	4
Logue Brook	24.6	22	3	2
Stirling	53.8	71	12	9
Wellington	185	22	6	3

* Note: a value of 5% of total storage was adopted for Waroona on the basis of historical drawdowns observed over the period 1980 to 2002.

From anecdotal information obtained during the course of this review it is understood that of the storages in this portfolio only Logue Brook Dam has significant likelihood of being drawn down prior to a flood occurring. The sensitivity of considering the joint probability of inflows and initial storage content for Logue Brook dam is speculatively assessed using around 30 years of historical (weekly) data. (It would be better to use longer term data based on current operating conditions, though the historical data is useful for illustration purposes. Note also that correlation between the initial storage contents and inflows has been ignored, and further investigation would be required to confirm whether it should be incorporated).

The results obtained allowing for drawdown are illustrated in Figure A-11. While the results are based on design rainfalls and historic reservoir conditions relevant to Logue Brook, the results are obtained using loss model parameters that are not calibrated to the catchment. In addition, the results shown are for a 24 hour event and it may be that another duration is more critical. To provide a useful benchmark for comparison a notional Dam Crest Flood has been selected that has around a 1:5000 AEP of being exceeded, a likelihood that has been estimated by the Water Corporation to represent the current hydrologic risks of overtopping for Logue Brook.

It is clear from this analysis that the consideration of drawdown may have a large influence on the estimated likelihood of overtopping failure. Depending on the assumption used of initial storage condition (and seasonality of distribution) the AEP of overtopping is seen to vary between 1 in 5000 AEP down to 1 in 150000 AEP. The results indicate that the joint probability analysis based on two seasons would severely underestimate the outflow flood frequencies.

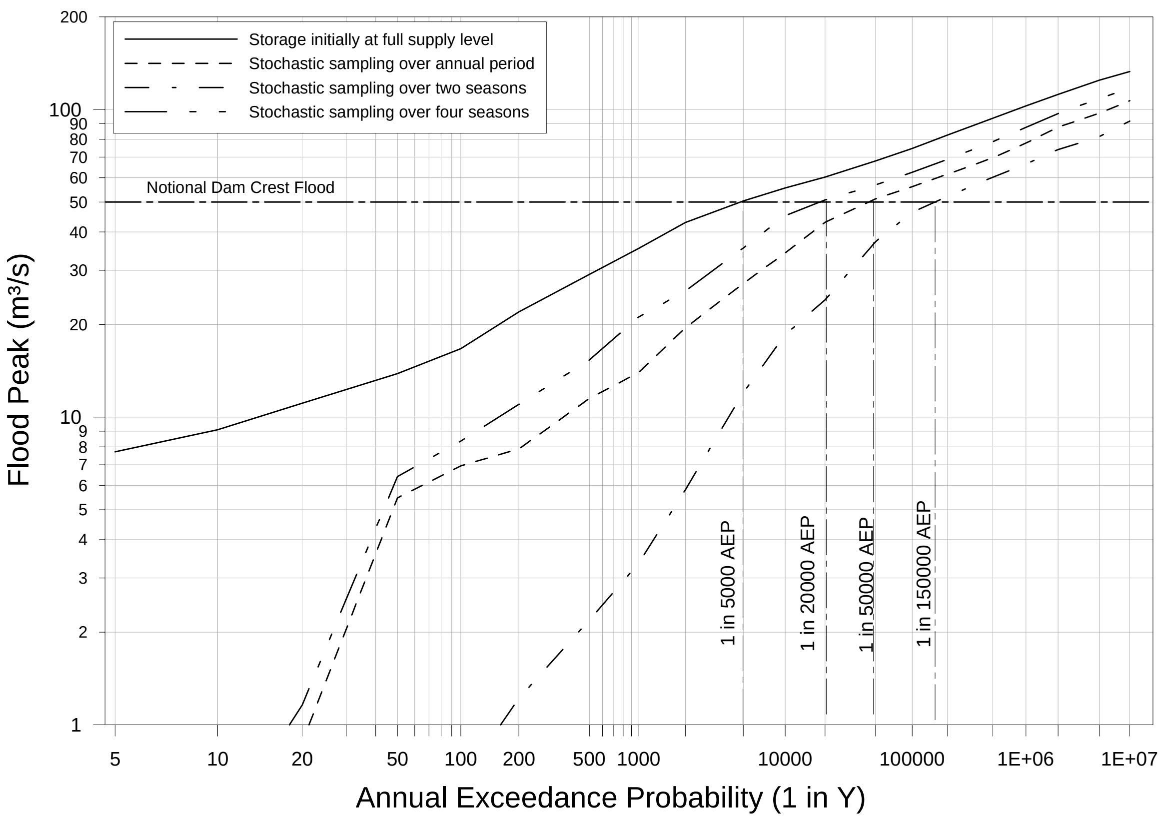

FIGURE A-11 SPECULATIVE RESULTS OBTAINED FOR CASE IN WHICH SEASONAL DRAWDOWN IS ALLOWED.

Sensitivity Analyses

The reports provided present the results of various sensitivity analyses, namely analyses related to future possible land-use effects of bauxite mining, greenhouse effect, and the uncertainty of parameter identification.

The sensitivity analyses undertaken to assess the impacts of bauxite mining are linked well to the conceptual basis of the loss modelling. Accordingly the results of such an analysis should be considered when making final design decisions.

The analyses related to assessing the impact of greenhouse effect are less defensible. There is considerable uncertainty regarding the likely direction and magnitude of greenhouse changes, particularly with respect to second-order effects such as those related to rainfall intensity. Either the basis for the stated increases in rainfall depths associated with the greenhouse effect are cited and/or explained, or else the results should be omitted as being potentially misleading.

The sensitivity analyses associated with parameter uncertainty that was undertaken in the earlier set of reports is potentially misleading in that they do not take into account that the parameter governing the non-linearity of catchment response is directly linked to that governing the degree of attenuation. It is noted that this sensitivity assessment has been omitted in later reports, though if corrected such sensitivity analyses would help illustrate how sensitive the results are to the parameterisation. To correctly reflect the stated uncertainty it would be necessary to identify the "anchor point" (say, the 1 in 100 AEP flood) at which there is good corroboration from independent evidence that the results are correct. Then, any sensitivity of either the catchment routing or non-linearity parameter should be assessed after the other parameter has been adjusted to match the accepted "anchor point". This approach thus focuses attention on the uncertainty introduced by extrapolating from conditions for which we have good evidence to those well beyond our observed records.

A.6 PMP versus PMPDF

At present the reports do not make a distinction between the PMP Design Flood and the Probable Maximum Flood. Given the influence of the soil moisture store and other factors there is a lot of potential for the magnitude of the floods resulting from the PMP to vary considerably. The distinction between these two extreme floods is only of relevance if a standards-based fix for the dams is required, and if the fall-back provisions of the ANCOLD (2000[a]) guidelines apply. This issue is discussed in Nathan et al. (2001), and an indication of the possible difference between the two flood estimates was explored using Monte-Carlo simulation.

Results were obtained for the Logue Brook catchment, using the 24 hour PMP rainfall as input and allowing all other factors to vary over four seasons. The distribution resulting from 5000 simulation is presented in Figure A-12. If the PMF is assumed to represent the flood value resulting from the PMP that is exceeded 10% of the time, then it is seen that the PMF is around 25% higher. The results for inflows are shown in Figure A-12, and a similar analysis of outflows (allowing for variations in drawdown) indicates an outflow PMF that may be 50% higher than the PMPDF value obtained using joint probability assumptions.

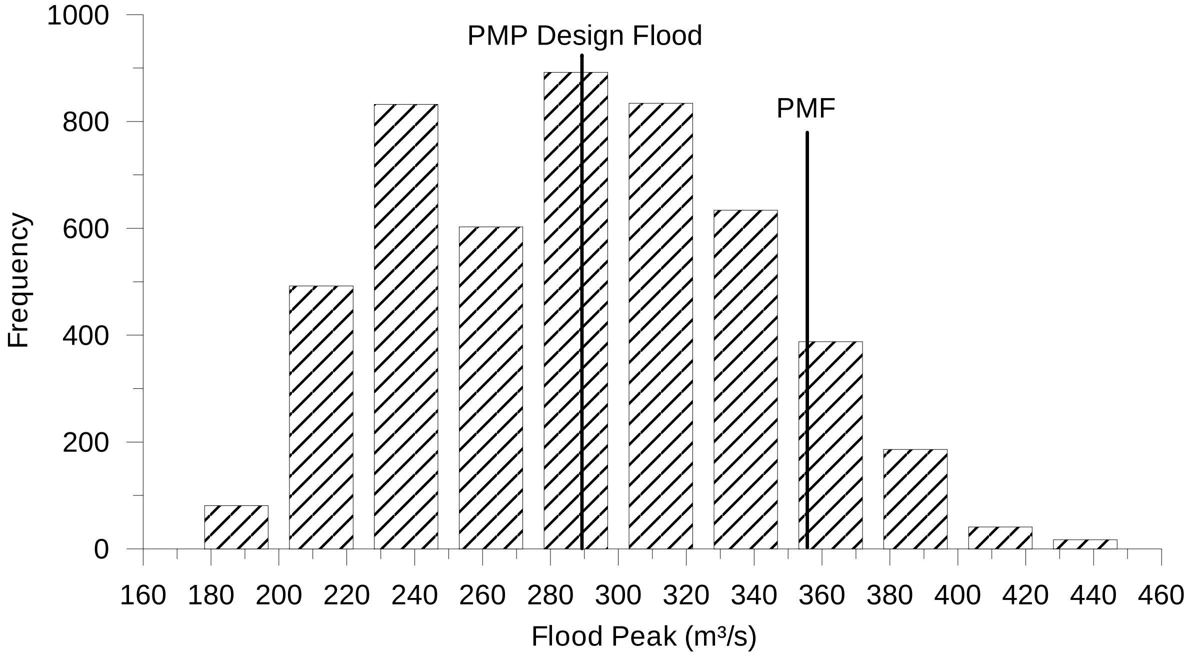

FIGURE A-12 DISTRIBUTION OF FLOOD PEAKS RESULTING FROM PMP RAINFALLS.

Appendix B