WORKING WITH SAFE DAMS

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ABSTRACT

A strategy designed to ensure that an existing dam continues to perform effectively will include:

- a set of operating instructions.
- maintenance of the reservoir components.
- an ongoing review of structural performance.
- a system to indicate the appropriate application of resources.
- the ability to respond to an incident.

This paper will explore each of these issues and how they may be applied to dams in a variety of situations. These situations include water supply reservoirs, flood retarding basins, levees and wastewater lagoons. While each situation is different, the underlying principles will remain consistent. The range of situations encountered by Victorian Water Authorities provides the inspiration for the development of an efficient approach to the management of the safety of dams.

KEY WORDS

Dam safety, consequence, failure modes, risk, audits.

1.0 INTRODUCTION

There was some hesitation in deciding to present a paper on dams to the Annual Victorian Water Industry Engineers and Operators Conference. Dams don't immediately come to mind when talking about water and wastewater treatment plants and chemical processes. However, in our work with Victorian Water Authorities on the management of their dams, it is apparent that dam safety is relevant at many locations. Water treatment plants are often situated adjacent to raw or clear water storages; lagoons are usually located near wastewater treatment plants and low lying plants may be protected by levees. So, perhaps we do have some synergy.

Changes are occurring in the way Victorian Water Authorities are managing their small dams. Large dams obviously need top line expertise and attention. But the large number of small to medium dams represent wide ranging risks to their owners. The introduction of corporate style management by Authorities has created a climate in which Board members are seeking assurances that dam safety management is being conducted in a way that keeps their organisation "out of trouble". The ultimate trouble would involve a breach and uncontrolled outflow, possibly causing loss of life and certainly causing damage to property, infrastructure and the environment.

A dam is defined as an artificial barrier, together with appurtenant works, constructed for storage, control or diversion of water or other liquids, silt, debris or water borne material (ANCOLD 1994). This means that apart from water supply storages, dams are used to contain wastewater lagoons and for storage at water treatment plants, stormwater storage basins and flood levees. The consequences of a failure at any of these structures should influence the way they are managed.

Before the amalgamation of the Victorian Water Authorities during the 1980s and early 1990s, many dams were being neglected. As the scrub was cleared and surveillance programs commenced, a number of faulty embankments were discovered.

These have been or are being improved. During this period, the ANCOLD Guidelines on Dam Safety Management were being developed. This paper briefly outlines these guidelines and discusses subsequent developments such as consequence assessments, risk assessment and audits.

2.0 DAM SAFETY MANAGEMENT

Dam safety management processes have been developed for large water supply storage reservoirs. This was given a high priority during the 1970s and 1980s as a result of a number of spectacular dam failures. These failures include Teton Dam in Idaho, Vaiont in Italy and Malpasse in France.

The components of a dam safety management program include:

- Operations and maintenance.
- Surveillance (monitoring and inspections).
- Safety reviews (design review).
- Remedial action (upgrading, modified operation or abandonment).
- Dam safety emergency plans (response to a potential or actual failure).

The scale of these activities should be linked to the consequences of failure; the volume of the storage; the size of the dam; and the structural condition of the dam.

3.0 RECENT DEVELOPMENTS

In an effort to focus on the big picture and to ensure nothing is missed, Authorities are adopting a systematic approach to identifying deficiencies and establishing priorities for management and remedial action. A further development is to audit the dam safety management process to ensure that a process is in place and that it is working. These processes are being driven by the need to enable Board members, who may not have a technical background, to take ultimate responsibility for decisions which will achieve business objectives, but also involve public safety, environmental management and levels of risk.

3.1 Consequence Assessment

The consequences of a dam failure are based on the area of flooding and the depth/velocity of the flow. Once the flood zone is established an estimate can be made of the population at risk and the severity of the damage and loss. The combined effect of these two factors are expressed as a Hazard Category which is defined in Table 1, taken from the 1998 Draft ANCOLD Guidelines on Assessment of the Consequences of Dam Failure. The consequence assessment takes into account:

- Storage volume.
- Embankment or wall height.
- Extent of flood zone downstream of the dam.
- Width of the flood zone along the waterway.
- Population at risk.
- Damage and loss including costs, implications for the business, effects on the community and environmental effects.

The potential loss of life is not used in the consequence assessment. This issue involves complex issues such as warning times, escape routes and water flow depth and velocity, is left to the risk assessment.

The following example illustrates the estimation of the consequences and the allocation of a Hazard Category:

(a) Flood Affected Zone

The flood affected zone is based on the storage volume and the height of the embankment or wall. The downstream distance will vary with the topography, but typical distances may be used for preliminary estimates. Inundation maps should be established for important situations.

Total storage volume 180 ML

Estimated storage volume above natural surface level 180 ML
Embankment / wall height 8 m
Assessment distance downstream of the dam 5 km

The assessment distance used in this example was taken from the table below:

Basin Capacity (ML)	Possible Distance (km)
20000	60*
2000	20*
200	5
100	3
20	1.3
10	1.0
2	0.5

* ANCOLD 1998

Land use within the flood zone is identified as:

Type	Length Along the Waterway (km)
Forest	1.0
Parkland/Open Space	0.0
Residential	0.0
Industrial/Retail	0.0
Agriculture	4.0

(b) Population at Risk

The population at risk is the number of people who would by affected by the dam break flood. The potential loss of life would be a proportion of this number, depending on factors such as warning time, location and the time of day. The estimate should separate the locations of the population at risk according to distances downstream of the dam:

- <2 km to identify people at highest risk.
- 2 to 10 km for medium risk.
- >10 km for lower risk.

The type of location is useful information, such as:

- Dwellings
- Commercial
- Public buildings
- Recreation along the river
- Road crossings

For this example, the population at risk was estimated to be 7.

(c) Severity Levels of Damage and Loss

Severity levels may be divided into four groups to reflect different typed of damage (ANCOLD 1998). The guidelines contain a sample set of criteria for severity levels. These can be varied to suit circumstances within the portfolio. The example produced the following severities:

- Financial and economic = Minor
- Service and business = Medium
- Social = Minor

- Environmental = Minor

Overall damage and loss severity level = Medium

(d) Hazard Category

The definitive statement of consequence comes from Table 1. In this example, the Hazard Category = SIGNIFICANT. This means that the loss of life is unlikely, but the possibility is recognised. If one of the houses in the above example was less than 2 km from the dam, then the Hazard Category should be increased to HIGH.

Table 1: ***Hazard Categories***

Population at Risk	**Severity of Damage and Loss**			
	Negligible	**Minor**	**Medium**	**Major**
0	Very Low	Very Low	Low	Significant
1 to 10	Low Note 4	Significant Note 5	Significant Note 5	High
11 to 100	Note 1	Note 2	High	High
101 to 1000			High Note 3	High
More than 1000			Note 3	Extreme

Note 1: With a population at risk exceeding 5 people, it is unlikely that the severity of damage and loss will be "Negligible".
Note 2: "Minor" damage and loss would be unlikely when the PAR exceeds 10.
Note 3: "Medium" damage and loss is unlikely (but could be possible) when PAR exceeds 100.
Note 4: Change to *Significant* where it is possible that one life could be lost
Note 5: Change to *High* where it is possible for more than one life could be lost

NOTE: Later drafts of the guidelines will probably change this table slightly.

2.2 Risk Assessment

A risk assessment for a large portfolio of assets should be conducted in stages. The first stage should act as a filter to separate the most important assets with the more severe deficiencies. The Stage 1 risk assessment should identify actions needed to reduce the risk and recommend more detailed investigations, which may include complex risk assessments.

The risk assessment used at the early stages of the decision making process is based on:

- likelihood of failure;
- potential loss of life; and
- severity of damage and loss.

The severity of the damage and loss is taken directly from the consequence assessment. The potential loss of life is derived from the population at risk and the location downstream of the dam. A possible way of estimating this for a particular portfolio is shown in Table 2.

Table 2: ***Estimates of Potential Loss of Life for Portfolio Risk Assessments***

Situation of the Population at Risk		Potential Loss of Life				
Size of Community	**Distance Downstream of the Dam**	**PAR = 0**	**PAR = 1-10**	**PAR = 11-100**	**PAR = 101-1000**	**PAR = >1000**
No people at risk		No people at risk				
Scattered dwellings	<2 km		Expected ≤ 10			
	3 to 10 km		Reasonable possibility of one			
	>10 km		Unlikely but possible			
Small community, say 10 to 30 dwellings	<2 km			Expected ≤ 10		
	3 to 10 km			Reasonable possibility of one		
	>10 km			Unlikely but possible		
Large community, say 30 to 250 dwellings	<2 km				Expected > 10	
	3 to 10 km				Expected ≤ 10	
	>10 km				Reasonable possibility of one	
Towns or cities (>250 dwellings)						Expected > 10

Failure may occur under loading conditions such as flood, earthquake or normal operating conditions. Within each of these loadings, modes of failure for embankments include:

- Embankment breach by overtopping and erosion.
- Embankment breach by internal erosion.
- Spillway or overflow failure.
- Uncontrolled flow from the outlet works.

The likelihoods are determined by evidence of deficiencies and dams engineering experience and judgement. Risk can be described in terms of matrices as shown in Table 3. The highest risk is on the top right box and the lowest is on the lower left.

The horizontal scale can be potential loss of life or severity of damage, depending on the detail required. Acceptance levels can be established within the matrix to distinguish the assets where remedial action or further investigation is required. The Authority must establish the level of risk it is prepared to accept.

Table 3: ***Risk Matrices***

Likelihood	**Hazard Category**

of Failure	Very Low	Low	Significant	High	Extreme
Highly Likely					
Likely					
Possible					
Unlikely					
Highly Unlikely					

2.3 Audits

The ongoing dam safety process can be independently audited to ensure the procedures are in place and are being followed. The aims are to:

- establish a record of performance;
- indicate gaps between performance and standards; and
- provide a reference point for the next audit.

Questions asked during the audit relate to matters such as:

General	♦ Technical standards and documented procedures need to be available and understood by personnel. ♦ They should be controlled documents and their implementation verified. ♦ Resources should be available to carry out the tasks. ♦ Staff training.
Storage Operations	♦ Non-typical and emergency operations procedures, such as planned maintenance shutdowns and floods. ♦ Environmental management.
Structural Maintenance	♦ Identification of the components which need to be maintained. ♦ Planned maintenance targets and their achievement. ♦ Backlog because of unplanned maintenance. ♦ Priority ratings for maintenance tasks. ♦ Maintenance records.
Dam Surveillance	♦ Conduct of minimum monitoring tasks. ♦ Management of information about structural performance. ♦ Conduct of inspections.
Safety Reviews and Capital Works Program	♦ Conduct of past reviews and the program for future reviews. ♦ The capital works program should be prioritised and on time.
Dam Safety Emergency Management	♦ Issues to be included are the responsibilities of personnel; resources; levels of emergency relating to dam safety events; and communication and coordination with emergency management agencies and others

3.0 CONCLUSIONS

Dam owners should maintain a level of safety that is commensurate with the consequences of failure.

Priorities should be set by combining the consequences of failure with the likelihood of a failure occurring.

A periodic independent audit will focus the attention of staff on quality management and provide a means of communicating with top echelons of the organisation.

Some of these principles could be applied to other assets, such as treatment plants, etc.

4.0 REFERENCES

ANCOLD Guidelines on Dam Safety Management (1994).

Draft ANCOLD Guidelines on the Assessment of the Consequences of Dam Failure (July 1998).

5.0 ACKNOWLEDGEMENTS

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- Dam Safety Management (1994)
- Assessment of the Consequences of Dam Failure (Draft July 1998).