Spillway Design and Review Procedures for Australian Farm Dams — Preliminary Results

A report for the Rural Industries Research and Development Corporation

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Foreword

Farm dams are a key component of most agricultural systems. However, these dams, even small ones can be a threat to life, property and the environment. If a dam fails, the cost to both the landholder and the community downstream could be significant.

Until now, the cost of accessing professional advice about dam design and safety has resulted in it being out of the reach of many landholders.

This publication provides preliminary information on a more affordable process to assist those seeking professional advice in South Eastern Australia. It establishes a procedure which in essence involves the application of a series of complex calculations. By applying these calculations, the spillway and storage capacity of the dam can be readily reviewed or designed. In addition to the process being simple and affordable, importantly modern engineering best practice principles are being met.

This project was funded from RIRDC Core Funds which are provided by the Australian Government.

This report is an addition to RIRDC’s diverse range of over 1000 research publications, forms part of our Resilient Agricultural Systems R&D program, which aims to foster the development of agri-industry systems that have sufficient diversity, integration, flexibility and robustness to be resilient enough to respond opportunistically to continued change.

Most of our publications are available for viewing, downloading or purchasing online through our website:

- purchases at www.rirdc.gov.au/eshop

Simon Hearn
Managing Director
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Executive Summary

Up until now, the cost of accessing professional advice about dam design and safety has resulted in it being out of the reach of many landholders. In order to help address this problem, a more affordable process to assist those seeking professional advice has been developed and is presented here. This report describes the process used and results obtained in the development of a cost-effective spillway design/review procedure for small dams in Southeastern Australia.

The development process primarily involved deriving regionalised Dam Crest Flood capability prediction relationships for reservoirs on small rural-type catchments using the RORB engineering model in line with modern best practice. Such relationships had already been developed for South Australia (Pisaniello PhD Thesis), and preliminary relationships only had been developed for Victoria as a result of previous research undertaken at the University of South Australia. The current study has significantly progressed the Victorian relationships and also well established preliminary relationships for NSW.

In total, 12 “representative” catchments in NSW and 6 catchments in Victoria have been hydrologically modelled, and extended flood studies of hypothetical dams placed on the same catchments have then been conducted. The hypothetical dams represent a wide range of reservoir conditions and spillway capacities up to the Probable Maximum Flood (PMF). Appropriate analysis has led successfully to the derivation of regionalised relationships based on simple hydrological/hydraulic variables, for predicting reservoir flood capability as either Annual Exceedance Probability (AEP) or %PMF. It is this output which is checked by an engineer against modern best-practice safety criteria in order to either determine the adequacy of an existing spillway and/or the necessary size of an appropriate spillway.

This establishes a reliable and credible procedure that will encourage better and more uniform private dam design and safety management in both NSW and Victoria. The procedure is applicable to dams on small catchments up to 100 km² in size in NSW and up to 20 km² in size in Victoria: this will usually cater for most private dam cases in each State.

In essence, applying the procedure in “review mode” merely requires (1) a short site visit by an engineer in order to measure a few simple necessary parameters (for example, spillway width and heights, embankment height and reservoir and catchment area), (2) input of these parameters into the developed regionalised prediction relationships in order to determine the spillway flood capability of the dam and then (3) checking this result against current best-practice safety criteria which is incorporated in the prediction relationships. When used in “design mode”, the same basic parameters are related to a proposed reservoir, or upgrade of an existing reservoir. The parameters are varied iteratively in the same regional prediction relationships until the best-practice safety criteria together with the owner’s storage needs are satisfied. Therefore, the process can be applied either in the checking of existing dams, the re-design of existing dams or the design of new structures. Both spillway and storage designs can be tailored to suit the surrounding landscape and the storage requirements of the landholder. The resulting design information is presented graphically for both landholders and construction contractors.

The regional relationships upon which the procedure is based are being developed by an Australian Research Council (ARC) Discovery project, which will further extend this research via a “community partnerships” approach. While the catchments utilised in both NSW and Victoria represent reasonable “State-wide” spread, it will be appropriate for future studies to undertake works on additional catchments within each region in order to increase confidence in the developed design/review relationships applying to the entire area within each region. The Discovery project is entitled ‘cost-effective integrated engineering and ‘community partnerships” solution to a latent water policy issue: private dam management and flood safety’ and is due for completion by the Water Policy and Law Group at the University of South Australia in 2005. Nevertheless, as they
stand here, all relationships display excellent predictive accuracies, therefore enabling them to be used in practice with confidence.

The main benefit of the procedure is it reduces the effort and resources that are normally required by an engineer for conducting a “state of the art” reservoir flood capability study. The procedure provides a basis for quick yet accurate review and/or design of private dam spillways against any design flood standards. At the same time, it is in line with modern acceptable practice which is of critical importance in a court of law to satisfy the requisite duty of care, that is: to avoid negligent liability in the event of dam failure and subsequent litigation.

Often landholders hire contractors to construct their dams, who are not properly trained or skilled in designing and constructing of dams, nor in taking account of the recent changes in engineering practices and upward revisions of rainfall and flood data. Thus, many dams have not been built to an adequate standard: this is currently a worldwide problem. Hence, a clear need has developed for dam owners to review the spillway flood capabilities of their dams, and upgrade if necessary, in order to meet their duty of care and avoid liability for possible failure consequences.

The commercial potential of the procedure is significant in regions where spillway safety review is mandatory by legislation, and the demand for the procedure becomes somewhat assured. In Victoria alone there are some 800 farm dams which have been identified as requiring review. Therefore, the key details of the design-review relationships as developed in this study have been kept confidential in order to avoid any persons using the relationships and charging unreasonable fees before they are even finalised by the future ARC research. Once the relationships are finalised, various options will be assessed as to how best ensure that the cost-effective benefits of the procedure are not abused, but rather passed on to the farming community. For example, licencing the procedure to a number of engineering firms and then relying on market forces to ensure that the savings are passed on, or perhaps establishing a new “farmer-friendly” company that will deliver the spillway service at a cost-effective price. In the meantime, any landholders requiring the cost-effective service based on the “useable” procedure presented here can contact Dr John Pisaniello at the University of South Australia (ph: +61 8 8302 0031), and an interim review can be organised via the University’s “controlled” business services.

Overall, bringing the curves together here from each of the three States, NSW, VIC and SA, has successfully established a mechanism applicable to the whole of Southeastern Australia. The project has gone a long way in establishing a scientifically acceptable procedure that will promote consistency and uniform standards and strongly encourage better private dam design and safety management in Southeastern Australia. This will set a precedent for the remaining States to follow so as to ultimately develop a mechanism applicable Australia-wide.
1. Introduction and Project Scope

Australia has a large number of relatively small, privately owned dams (farm dams in particular): those which have failed number in the thousands. A large proportion of these dams are located in Victoria and NSW. For example, Victoria has an estimated 170,000 farm dams, 800 of which are large enough to cause serious consequences downstream if they failed (ANCOLD, 1992; Murley, 1987); at least ten significant failures have occurred in Victoria in the last decade (Lewis and Harrison, 2002); while ANCOLD (1992) reports that the failure rate of farm dams in NSW is 23 percent. The growth of farm dams in these States is also increasing at a rapid rate. For example, in the Victorian Lal Lal Reservoir catchment alone (234 km$^2$), farm dams increased in number from 182 in 1970 to 534 in 1985, representing an increase of about 200% (GHD, 1987). When these dams were constructed, the majority more than 20 years ago, their designs were based on rainfall frequencies and intensities, design methods and criteria and standards of risk available at that time. However, these aspects have changed over time, together with population distributions and the condition of the dams, raising serious doubts about dam adequacy.

In modern times, the major concern with dam safety worldwide is the provision of adequate spillway flood capability. This is mainly because significant advances made in the fields of meteorology and flood hydrology have updated both maximum probable rainfalls and design flood standards above those on which most existing dams were based. As a result of these revisions, many dams have insufficient spillway capacities.

In Australia, the Australian National Committee on Large Dams (ANCOLD) sets the standard for acceptable flood capacity of dams. For example, Significant Hazard Potential dams, generally defined as those which may endanger life and will cause extensive damage upon failure, are required to have a spillway large enough so that its likelihood of failure is no more frequent than once in 1000 years. However, a study undertaken by Pisaniello (1997) of a sample of significant farm dams in South Australia found that the dams fell well short of this standard 91% of the time. This trend is consistent with many other studies undertaken worldwide; see Pisaniello and McKay (1998) for further details.

In addition to this concern is the fact that most private owners hire contractors to construct their dams. These contractors are, typically, not properly trained or skilled in the design and construction of dams. Thus, many private dams are not built to an adequate standard. For example, the spillway may be too narrow, it may be poorly directed over the embankment so as to undercut and weaken the dam, or the layers of soil that make up the dam are not properly compacted.

Consequently, the recognition of risks associated with the dams has increased greatly. A need has therefore developed for owners to appropriately manage their dams in line with current standards in order to reduce the risks involved, reflect community standards and provide increased dam safety assurance to downstream communities.

In particular, owners should review the spillway flood capabilities of their dams, and upgrade if necessary, in order to avoid liability for possible failure consequences (McKay and Pisaniello, 1995). Unfortunately, the engineering processes involved are highly rigorous and time-consuming in practice and therefore generate high consulting fees, which in many cases are not affordable by private owners. For this reason, owners tend to overlook the need for reviewing their dams and instead develop a sense of complacency, believing that as the dams have not failed up to now, then they will never fail. The result is that dams are deprived of necessary upgrading and downstream communities are placed at risk.
Image 1: A typical spillway as previously built, with the black outline demonstrating the size that it should be if it was designed properly. It should also be redirected away from the embankment as illustrated by the arrow.

Image 2: A poorly designed spillway as it undercuts and weakens the dam wall: the potential exists for the wall to collapse at any time, particularly during a significant overflow event.
Unfortunately, there is a policy vacuum in Australia on private dam safety policy, except partially in NSW (Dams Safety Act, 1978) and Queensland (Water Act, 2000), but even their policies are not pervasive, ie: they only address the problems associated with the larger, more significant on-stream dams, without giving due consideration to the problems associated with the multitude of smaller off-stream dams. In contrast, in Victoria an attempt has recently been made to address this problem by incorporating amendments to the Water Act 1989. In particular, s67 now applies to significant “off stream” dams and requires their owners to obtain a licence to operate their dams. Under s71, licence conditions include dam safety requirements, eg standards of construction, surveillance, operation and maintenance. Rural Water Authorities set up around the State have been assigned the responsibility of administering the Act and the licencing requirements (DNRE Victoria, 2002). A significant step in Victoria has also been the publication of the booklet “Your Dam, Your Responsibility – A guide to managing the safety of farm dams” (DNRE Vic, 2002): this targets the smaller yet hazardous dams which are usually ignored and well educates dam owners on their responsibilities and potential liabilities. However, even in Victoria (as well as the other States) there is still a clear need for a mechanism that minimises review costs to private owners and in turn encourages better dam safety management.

The Rural Industries Research and Development Corporation (RIRDC), recognising this need awarded a grant to the Water Policy and Law Group (WPLG) at the University of South Australia to undertake a study based on the Pisaniello (1997) PhD thesis (see also Pisaniello & Argue, 1997), in order to help establish such a mechanism for Victoria and NSW. The study was also supported collaboratively by the Victorian Department of Natural Resources and Environment (DNREVic) and the NSW Department of Land and Water Conservation (DLWC NSW). This report describes the main procedures involved in the study and presents the resulting cost-effective flood capability design/review procedure. It should be noted that while the procedure presented here is useable, it is only interim in nature as significant works are being undertaken as part of an Australian Research Council (ARC) Discovery project to further develop the overall process. The Discovery project is entitled ‘cost-effective integrated engineering and “community partnerships” solution to a latent water policy issue: private dam management and flood safety’ and is due for completion by the WPLG in early 2005.
2. The Development Process

In order to encourage private dam owners to review and upgrade their spillways to meet current acceptable standards, Pisaniello (1997) developed a simple and cost-effective regionalised flood capability design/review procedure. This procedure is applicable in South Australia, but transferable to any other region, and is in line with current best practice, thereby promoting consistency and uniform standards. It is this transferral to both NSW and Victoria that will be undertaken in this study.

The Pisaniello (1997) procedure primarily involves the development of regionalised flood capability prediction relationships for dams on small rural catchments based on the Reservoir Catchment Ratio (RCR):

\[
RCR = f \{ SC, PI_{PMF}, RA, SH, CA, PI_{100}, PI_{50} \} 
\]

where:
- \( SC = \) spillway overflow capacity (m\(^3\)/s)
- \( PI_{PMF} = \) peak inflow for the PMF event (m\(^3\)/s)
- \( RA = \) reservoir area at Full Supply Level (km\(^2\))
- \( SH = \) maximum height of spillway overflow (m)
- \( CA = \) catchment area (km\(^2\))
- \( PI_{100} = \) peak inflow for the 100 year ARI event (m\(^3\)/s)
- \( PI_{50} = \) peak inflow for the 50 year ARI event (m\(^3\)/s)

For regions where no variation is observed in the Annual Exceedance Probability (AEP) of the Probable Maximum Flood (PMF), the RCR takes on the compact form:

\[
RCR = f \{ SC, PI_{PMF}, RA, SH, CA \} 
\]

It is notable that the above variables which form the basis of the RCR are all simple and easily determined by an adequately trained practitioner: this is why the procedure once developed is simple and cost-effective in nature.

Developing the RCR based on the Pisaniello (1997) procedure necessitates the collection and derivation of appropriate catchment and reservoir data in the study regions, and the formulation of a range of hypothetical dams (approximately 20) - using the RORB model (Laurenson and Mein, 1990) - on each catchment representing all possible scenarios up to the PMF event.

The complex process aims to represent the hydraulic response of any size of reservoir and spillway(s) relative to the hydrological flood response of the selected “regionalised catchment type” via the Reservoir Catchment Ratio.

The project involved two main components: (1) works in NSW to at least get a set of design/review relationships off the ground and (2) works in Victoria to help finalise the already developed relationships reported in Pisaniello and McKay (2000), see also Pisaniello et al (2001). These two main components will be discussed in detail below in Sections 3 and 4 respectively.
3. Development Results: New South Wales

In NSW, DLWC made available as in-kind support the results of a consultancy that it commissioned HECEC (Tas) to undertake of a safety audit of 13 small dams (DLWC Agreement No. 98/002): these data were used for the development of the design/review relationships in this State.

3.1. Delineating the NSW Regions

Most data from the DLWC Small Dams Consultancy was successfully sorted and collated and quality assessed in relation to the Pisaniello (1997) development process. A total of 8 “small” catchments ranging in size from 2.2 km$^2$ to 20 km$^2$ were initially found to be adequate for the purposes of this study. A further 4 catchments ranging in size from 20 km$^2$ to 91 km$^2$ were also found to be adequate, whilst in addition providing the opportunity to sensitise the design/review relationships for ‘catchment size’. Fortunately the locations of all 12 catchments were such that at least a pair was located in each of the 4 main regions of the State (as defined by DLWC):

- North Area
- South Area
- Central Area
- Coastal Area

These regions and study catchment locations are illustrated in Appendix 1. Catchment areas are summarised in Table 1. From Appendix 1, it is evident that a reasonable spread of catchments are represented Statewide. However, it will be appropriate for future studies to undertake works on additional catchments with much greater spread: this will further increase confidence in the developed design/review relationships applying to the entire area within each region and subsequently to the whole of NSW. This will be undertaken as part of the ARC Discovery grant discussed in Section 1.

Table 1: Catchment Areas of the NSW Study Catchments

<table>
<thead>
<tr>
<th>Dam No</th>
<th>Region in which catchment located</th>
<th>Catchment No within the region (per Appendix 1)</th>
<th>Catchment area (km$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>North Area</td>
<td>1</td>
<td>2.6</td>
</tr>
<tr>
<td>2</td>
<td>North Area</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>3</td>
<td>North Area</td>
<td>3</td>
<td>52.0</td>
</tr>
<tr>
<td>4</td>
<td>South Area</td>
<td>1</td>
<td>10.7</td>
</tr>
<tr>
<td>5</td>
<td>South Area</td>
<td>2</td>
<td>19.1</td>
</tr>
<tr>
<td>6</td>
<td>Central Area</td>
<td>1</td>
<td>4.9</td>
</tr>
<tr>
<td>7</td>
<td>Central Area</td>
<td>2</td>
<td>20.1</td>
</tr>
<tr>
<td>8</td>
<td>Central Area</td>
<td>3</td>
<td>24.7</td>
</tr>
<tr>
<td>9</td>
<td>Central Area</td>
<td>4</td>
<td>91.0</td>
</tr>
<tr>
<td>10</td>
<td>Coastal Area</td>
<td>1</td>
<td>2.2</td>
</tr>
<tr>
<td>11</td>
<td>Coastal Area</td>
<td>2</td>
<td>2.4</td>
</tr>
<tr>
<td>12</td>
<td>Coastal Area</td>
<td>3</td>
<td>66.0</td>
</tr>
</tbody>
</table>
Unfortunately none of the catchments were gauged, and therefore, no calibrated modelling results were available. Instead the DLWC Consultancy provided data based entirely on (1) the Dyer et al (1994) procedure for determining the RORB k\(_c\) parameter and (2) the Walsh et al (1991) procedure for determining design losses, which is in accordance with the Australian Rainfall and Runoff (AR&R: IEAust, 1999) guidelines for determining model parameters for ungauged catchments: hence, these data are adequate for use in the development of “useable” design/review curves for NSW as will be produced as a result of this pilot study. However, Pisaniello (1997) found that in order to produce generic regionalised curves that would be acceptable in a court of law, it is necessary to also try to base their development on gauged calibrated catchments (subject to the availability of catchments with adequate recorded rainfall and streamflow data): these will not only provide “best practice” data to the curves, but will also verify any data used based on the “next best” methods, eg. Dyer et al (1994) and/or AR&R (IEAust, 1999) regional prediction relationships (as has been done for Victoria, see Section 4, below). Hence, calibrated flood studies will need to be incorporated in future works to finalise the NSW design/review curves: again, this will be attempted as part of the ARC grant discussed in Section 1.

3.2. The Main Development Results

Design peak flow prediction equations for the 1 in 50, 1 in 100 and PMF events, {ie. scatter plots of catchment area (km\(^2\)) versus peak flow (m\(^3\)/s) in the logarithmic domain} were produced using data from all the 12 selected catchments obtained from the DLWC consultancy, and these are presented in Figures 1 and 2. The 1 in 50 and 1 in 100 peak flow prediction relationships in Figure 1 display an acceptable accuracy, but they were actually found to be unnecessary in the development of the design/review curves for this State (as was also found in Victoria). That is, the design/review relationships for this State could be based on the “compact” RCR per Equation 2, as all the study catchments resulted in an AEP of PMF = 1 in \(10^7\). From Figure 2 the PMF prediction relationship clearly displays a high level of predictive accuracy (ie. \(R^2=0.96\)): this is vital for successful development of the final design/review curves. Nathan et al (1994) derived a similar PMF prediction equation based on a sample of 56 catchments in South Eastern Australia, ranging in size from 1 km\(^2\) to 10,000 km\(^2\). The equation derived by Nathan et al (1994) was as follows:

\[
P_I\_{PMF} = 129.1 \cdot CA^{0.616} \quad (R^2 = 0.95)
\]
It was considered interesting, given the coincidence of regions, to compare the Nathan et al. (1994) prediction equation with that derived in this study. This comparison is presented in Figure 3.

The comparison in Figure 3 shows that the Nathan et al. equation if applied directly to the NSW cases of this study would slightly overestimate the peak PMF flows of the smaller catchments. This may be accounted for by either differences in hydrological regimes (South-Eastern Australia versus NSW) or differences in catchment sizes examined in the two studies. However, for catchment areas between 20 km² and 100 km², the relationships are remarkably similar. This suggests that the Nathan et al. equation is likely to be more biased towards larger catchments.
The Pisaniello (1997) processes were then applied to the study catchments: this involved creating a number of hypothetical dam cases (around 200 in total), at the outlets of the selected catchments, comprising varying size reservoirs and spillways and undertaking works to produce a wide range of flood capability outcomes up to the Probable Maximum Flood (PMF). The spillways must be free flowing and weir-type in nature. A good variety of cases was obtained by either: (1) widening the spillway, (2) raising the top of the crest which increases spillway height, (3) deepening the spillway which increases spillway height and decreases reservoir surface area and storage capacity or (4) raising the entire embankment and spillway which increases reservoir surface area and storage capacity. The process aims to represent the hydraulic response of any size of reservoir and spillway(s) relative to the hydrological flood response of the selected “catchment type” via the Reservoir Catchment Ratio (RCR), see Equation 2.

The design peak flow prediction equation for the PMF event from Figure 2 was then substituted into the RCR to produce the Regionalised Reservoir Catchment Ratio (RRCR) applicable to the sample region as follows:

\[
RCR = 61.84 \cdot CA^{0.8117} \cdot f\{SC, RA, SH, CA\}
\]  

(4)

The resulting flood capability (known as Dam Crest Flood, DCF) outcomes were used to create a scatter plot of RRCR versus DCF, representing the entire State as illustrated in Figure 4.
Figure 4: Sample Data for DCF Prediction using RRCR According to each of the NSW Sample Regions and Catchments

A line of best fit was then drawn through the scatter plot and the associated regression equation determined, thus producing the required reservoir flood capability prediction relationship as presented in Figure 5.
The coefficient of determination ($R^2$) for the relationship presented in Figure 5 has come in at 0.8817 (ie 88%): this suggests a good level of predictive accuracy. This means that any dam in NSW (with catchment area up to 100 km$^2$) can be assessed and/or designed with a high level of accuracy and confidence using this prediction relationship and input of the simple parameters described in Section 2 (see Section 5 for further details on how to apply the relationship). This is an extremely positive result given that this relationship represents the whole of NSW, and that it can still be broken down into 4 sub-curves, which will better represent the 4 main regions of the State. That is, sub-curves each representing smaller regions but with much better individual prediction accuracies as presented in Figure 6.
The prediction accuracies of the regional sub-curves displayed in Figure 6 are markedly improved from the accuracy of the State curve (of Figure 5), with the exception of the Coastal sub-curve which has slightly lost accuracy. In actual fact, based on past experience, the accuracies of each of the sub-curves were expected to be $R^2 = 0.95$ or better. This has not occurred here for two of the regions, and it was suspected that the use of overly large catchments was a contributing factor. To investigate this, the three largest catchments (see Table 1) were removed from the data set as follows:

- the 52 km$^2$ catchment removed from the North Area data set
- the 66 km$^2$ catchment removed from the Coastal Area
- the 91 km$^2$ catchment removed from the Central Area

### 3.3. Sensitising the Developed Relationships for Catchment Size

Following the removal of the three largest catchments, the data set now comprised 9 catchments, still with at least a pair contained in each sub-region of the State, but no catchment having an area greater than 25 km$^2$. A new PMF prediction equation (again for substitution into the RCR) was then determined based on the smaller catchments data set and is presented in Figure 7.
From Figure 7 the PMF prediction relationship clearly displays a high level of predictive accuracy (ie. $R^2=0.975$): this is an improvement on the accuracy previously obtained for the 12 catchments up to 100 km$^2$ in size (see Figure 2), and will translate well in the development of the final design/review curves.

Similarly as before, the design peak flow prediction equation for the PMF event from Figure 7 was substituted into the RCR to produce the Regionalised Reservoir Catchment Ratio (RRCR) applicable to the sample region, and based on catchments up to 25 km$^2$ only, as follows:

$$RCR = 59.379 \cdot CA^{0.8367} \cdot f\{SC, RA, SH, CA\} \quad (5)$$

The flood capability (DCF) outcomes were again used to create a scatter plot of RRCR versus DCF, representing the entire State as illustrated in Figure 8.
The coefficient of determination ($R^2$) for the relationship presented in Figure 8 is an improvement on that of Figure 5, suggesting that excessively large catchments (ie greater than 25 km$^2$) do indeed cause a loss in accuracy in the RRCR predictive capability. This is also demonstrated in the corresponding regional sub-curves presented in Figure 9. Comparing Figure 9 with Figure 6, it is clear that the predictive accuracies of the regional sub-curves is improved markedly when the data set is based on catchments no larger than 25 km$^2$: the improvement being most significant for the Coastal sub-curve where the $R^2$ has improved from 0.85 to 0.97.
While the predictive accuracies obtained for the data set containing catchments up to 100 km$^2$ (see Figures 5 and 6) are by no means unacceptable and could still be applied, accuracies better than $R^2 = 0.9$ are preferred: such accuracies have been obtained in Figures 8 and 9 for the data set containing catchments up to 25 km$^2$. The relationships are limited to small rural catchments (up to 25 km$^2$) as large catchments usually contain numerous flow attenuating storages upstream of the principal reservoir, which contribute to a non-systematic, case specific type flood response. Nevertheless, design/review relationships applicable to catchments up to 25 km$^2$ in size (per Figures 8 and 9) are more than adequate for farm dams as farm dam catchments are rarely greater than 10 km$^2$ let alone 25 km$^2$. If in the rare circumstance a farm dam does have up to 100 km$^2$ catchment area, then Figures 5 or 6 could still be used with relatively high confidence; in actual fact with very high confidence if the catchment does not lie in the Coastal area of the State. This means that any dam in NSW with catchment area between 25km$^2$ and 100 km$^2$ can be assessed and/or designed with an acceptable level of accuracy and confidence using these prediction relationships and input of the simple parameters described in Section 2. At the same time, if the dam has a catchment area up to 25 km$^2$, then it can be assessed and/or designed with almost perfect accuracy and confidence.

The flood capability relationships presented above form the main part of the overall design/review mechanism presented later in Section 5. Section 5 well explains how the mechanism can be applied in either review or design mode, where review mode enables the spillway of any existing dam to be checked against modern best-practice safety criteria, while design mode enables the spillway and storage capacity to be either re-designed for an existing dam or designed for a new dam.
3.4. Relationship for Determining Flood Capability as %PMF

From the flood capability studies undertaken for each case, DCF capability was also determined as %PMF. This was done in case minimum safety criteria have to be met that are based on %PMF rather than 1/AEP, as is the case with the dams supervised by the NSW Dams Safety Committee (NSW DSC, 1993). The %PMF outcomes were plotted against RRCR for both the data set representing catchments up to 100 km² and the data set representing catchments up to 25 km², establishing the relationships presented in Figures 10 and 11 respectively. These relationships complement the previous relationships in that they provide the option of determining any flood capability as “%PMF Inflow” rather than 1/AEP (years).

![Figure 10: Sample Data and Line of Best Fit for Determining DCF as %PMF applicable to Catchments up to 100 km²](image1)

![Figure 11: Sample Data and Line of Best Fit for Determining DCF as %PMF Applicable to Catchments up to 25 km²](image2)
Comparing Figure 10 with Figure 11, it is again clear that the predictive accuracy of the relationship improves when the data set is based on catchments no larger than 25 km$^2$. Nevertheless, both relationships provide a coefficient of determination better than 0.9. Therefore, the regressions enable satisfactory determination of flood capability as %PMF: Figure 11 is applicable to catchments up to 25 km$^2$ in size, and if in the rare circumstance a farm dam does have up to 100 km$^2$ catchment area, then Figure 10 could still be used with confidence.
4. Development Results: Victoria

In Victoria the need for the cost-effective design/review procedure was first identified in 1999 by the Department of Natural Resources and Environment (DNRE) which led them to funding a University of South Australia pilot study, reported in Pisaniello and McKay, 2000, see also Pisaniello et al, 2001. This study established appropriate calibrated data that could be used to develop the flood capability prediction curves for various regions of the State. These results were made available by DNRE as in-kind support to the RIRDC project as described below.

4.1. Primary Victoria Works

In the original DNRE pilot study, only 3 small gauged catchments with reasonable historic data were available in the State for the development process, these being of size 5.1 km², 6.4 km² and 11.2 km². Fortunately, these were reasonably well spread throughout the State and for the purposes of the DNRE study were considered to represent the three main regions of the State relative to the Great Dividing Range (GDR):

1. Barringo Ck. GS 230209
   (Area = 5.1 km², 20 yrs record): Central GDR (ie. mountainous region)
2. Shepherds Ck. GS 415244
   (Area = 6.4 km², 20 yrs record): Inland side of GDR
3. LittleAire Ck. GS 235204
   (Area = 11.2 km², 40 yrs record): Coastal side of GDR

The locations of these catchments are illustrated in Appendix 2. Pisaniello and McKay (2000) found that the coastal region warranted further subdivision into East and West regions in order to include cases which represent the Gippsland zone. This would increase confidence in the developed prediction relationships applying to the whole of Victoria, and was therefore adopted as one of the prime objectives of the study described here.

The calibration flood studies undertaken for these catchments resulted in abnormally high and erratic RORB \( k_c \) model parameters. This nevertheless led to the development of highly accurate design/review curves, but of non-conservative nature. The main relationship is illustrated in Appendix 3, Figure 3.1. This relationship also lacked credibility due to the lack of “catchment size” representation and distribution: resolving this was therefore adopted as another prime objective of the study here (see Section 4.2 below).

The original DNRE study also sensitised the relationships to lower RORB \( k_c \) parameters which represented the “most conservative” extreme, and which would also artificially represent a wider range of small catchment sizes, but not catchment distribution. This sensitivity analysis involved only “roughly” reconstructing the flood capability prediction curves by lowering the RORB model parameters for only a few of the original data points. This resulted positively in a relatively narrow band within which any refined curves (developed in future) would lay, as illustrated in Appendix 3, Figure 3.2. It is such refined curves, based on a complete set of data points, which have been produced as part of the RIRDC project (as presented in Appendix 4), and then further developed (as discussed in Section 4.3 and Section 5, below) in order to make them “useable” to dam owners.
In addition, the rough design/review curves that were developed as part of the DNRE pilot study were based on the old AR&R (IEAust, 1987) procedures for determining Annual Exceedence Probability (AEP) of the Probable Maximum Flood (PMF). As AR&R (1987) was superseded by AR&R (IEAust, 1999, published 2000), these curves were in need of revision in accordance with the new procedures. This was another main objective of the RIRDC project that turned out to be a more lengthy process than originally anticipated, as most of the works undertaken in the DNRE pilot study required re-doing. Nevertheless, as expected the revised curves (see Appendix 4) resulted in similar accuracies to the original curves (see Appendix 3) but with different slopes. It should be noted that “flood capability” is referred to as Imminent Failure Flood (IFF) in Appendix 3 and Dam Crest Flood (DCF) in Appendix 4 and throughout this report: this change to DCF is in line with the revised terminology adopted in ANCOLD (2000).

4.2. Additional “Smaller Catchment” Works in Victoria

4.2.1. Selection of additional catchments

As discussed in Section 4.1, the relationships developed as part of the DNRE pilot study (illustrated in Appendix 3) and re-developed as part of the current study (illustrated in Appendix 4) lacked credibility due to the lack of “catchment size” representation and distribution. From Appendix 2 it is apparent that:

♦ For the Coastal side of the GDR, representation would be required in the Gippsland region;
♦ Central region representation was already adequate given the relatively “central” locations of the Shepherds Creek and Barringo Creek catchments;
♦ For the Inland side of the GDR the “unrepresented” area is large and therefore at least two well-spaced catchments would be required for adequate representation.

Hence, the above deficiencies were addressed in the current study by the introduction of an additional 3 ungauged catchments:

Catchment 4: Boggy Ck.  
(Area = 2.15 km²): Gippsland region (ie. Coastal side of GDR)

Catchment 5: Wimmerra River  
(Area = 4.12 km²): Inland side of GDR

Catchment 6: Skeleton Ck.  
(Area = 1.13 km²): Inland side of GDR

The locations of these additional catchments are illustrated in Appendix 2.

4.2.2. Catchment modelling

The RORB program (Laurenson and Mein, 1990) was used for modelling; catchment and sub-area delineations were made using 1:25,000 scale topographic maps. All catchment, reservoir flood capability and PMF studies were undertaken in accordance with Australian Rainfall and Runoff (AR&R) (IEAust, 1987 and 1999, Book VI) and Bulletin 53 (BoM, 1994). Design rainfall information and design losses for the selected catchments for events between the 20-year ARI and the PMF were determined using the procedures described in AR&R (1987 and new edition) and Hill et al (1996).
However, a decision had to be made on what RORB $k_c$ modelling parameter would be used for each catchment. From the DNRE pilot study, based on the three original gauged catchments (see Appendix 2), $k_c$ parameters were determined using the following three methods (in decreasing order of certainty):
1. calibrating the gauged catchments and obtaining the “best” calibrated results.
2. Andrew’s Fourier Plots (Dyer et al, 1994).
3. regionalised prediction equations presented in AR&R (IEAust, 1987).

The results are presented in Table 2 and show that, in general, there exists significant variation between the AR&R (IEAust, 1987) and Andrews Curves results and/or the Best Calibrated results; Little Aire Creek being somewhat of an exception. The erratic nature of these results was seen to have the potential to impact adversely on the final design/review curves. Hence, as discussed under Section 4.1, a sensitivity analysis was initialised as part of the DNRE pilot study and completed for the RIRDC study.

Table 2: Comparison of RORB Parameters as Determined from Various Sources (after Pisaniello and McKay, 2000)

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<tr>
<td></td>
<td>(m$^3$/s)</td>
<td>$k_c$</td>
<td>$m$</td>
<td>$k_c$ (m=0.8)</td>
</tr>
<tr>
<td>May 1974</td>
<td>1.76</td>
<td>13</td>
<td>0.8</td>
<td>5.3</td>
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<tr>
<td>July 1990</td>
<td>0.88</td>
<td>7</td>
<td>0.8</td>
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<td>(m$^3$/s)</td>
<td>$k_c$</td>
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<td>$k_c$ (m=0.8)</td>
</tr>
<tr>
<td>Sep 1984</td>
<td>5.13</td>
<td>11.2</td>
<td>0.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Jan 1987</td>
<td>2.91</td>
<td>13.0</td>
<td>0.8</td>
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<tbody>
<tr>
<td></td>
<td>(m$^3$/s)</td>
<td>$k_c$</td>
<td>$m$</td>
<td>$k_c$ (m=0.8)</td>
</tr>
<tr>
<td>Jun 1978</td>
<td>24.5</td>
<td>7.0</td>
<td>0.7</td>
<td>7.6</td>
</tr>
<tr>
<td>Oct 1976</td>
<td>19.2</td>
<td>7.5</td>
<td>0.8</td>
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The sensitivity analysis involved re-developing RRRCR relationships using the lowest $k_c$ values for the two smaller gauged catchments (as provided by the Dyer et al procedure, see Table 2). This meant generating a complete design/review curve representing the “most conservative” extreme for comparison against the original “non-conservative” curve (obtained from the calibrated results), and therefore, a
practical operative band for future decision-making. The main comparison is presented in Figure 12: this demonstrates minimal separation between the conservative and non-conservative curves, with the curves actually converging towards the PMF. This was very encouraging considering the wide range of $k_c$ values that the curves represented, i.e.: the RRCR absorbs much of the impact of $k_c$ variance. Given this result, it was decided that an in-between position for the $k_c$ value would be appropriate: from Table 2, an in-between position is best provided by the AR&R method of determining $k_c$. While the certainty of the AR&R method is generally not as good as the Dyer method, it was considered appropriate to adopt here for Victoria because:

1. A study undertaken by Perera (1999) investigating 32 rural Victorian catchments found that in the Dyer method, selection of the “Andrew’s type” curve for ungauged catchments was extremely difficult in computing $k_c$: in many cases a subjective judgement had to be made. Perera concluded that the “type” curve is highly sensitive in determining the RORB $k_c$ for ungauged catchments which in turn effects the flood hydrograph – for the 32 catchments studied, the method contributed significantly to overestimating the peak flow rate when tested against more reliable frequency estimates.

2. The AR&R results in Table 2 are more comparable to the calibrated results which under normal circumstances are considered the most certain, as also evidenced by Perera (1999).

Therefore, given the above, the RORB model parameter $k_c$ for the additional 3 catchments was determined using the “in-between” AR&R (1987) prediction equations method.

In order to then create the flood capability prediction relationships, it was necessary to produce a wide range of flood capability outcomes relating to embankment dams placed at the outlets of the regional catchments. Similar to NSW, the aim of the process is to represent the hydraulic response of any size of reservoir and spillway(s) relative to the hydrological flood response of the selected “catchment type” (Pisaniello, 1997). This was achieved for Victoria by performing the following:
• Creating numerous hypothetical dam cases, 75 in total, at the outlets of the three selected catchments, comprising of varying size reservoirs and spillways which will produce a wide range of flood capability outcomes up to the PMF. The spillways must be free flowing and weir-type in nature. A good variety of cases was obtained by either: (1) widening the spillway, (2) raising the top of the crest which increases spillway height, (3) deepening the spillway which increases spillway height and decreases reservoir surface area and storage capacity or (4) raising the entire embankment and spillway which increases reservoir surface area and storage capacity.

• Including each of the hypothetical dams as ‘special storages’ in the created RORB models of their respective catchments.

• Determining design rainfall information and design losses for the selected catchments for events between the 20 year ARI and the PMF using the procedures described in AR&R (IEAust, 1987 and new 1999 edition) and Hill et al (1996).

• Using the RORB program to route flood hydrographs through each of the hypothetical storages to determine peak inflow, peak outflow and water elevation for all events up to the PMF.

• Producing a design peak flow prediction equation for the PMF event, ie. scatter plot of catchment area (km$^2$) versus peak flow (m$^3$/s) in the logarithmic domain. This equation when substituted into the RCR establishes a Regionalised Reservoir Catchment Ratio (RRCR).

• Using the determined peak inflows and elevations to establish peak inflow-frequency and elevation-frequency relationships for each dam. With these relationships the Dam Crest Flood (DCF) capability of each dam is determined as 1/AEP (years) and %PMF. The DCF is taken as the smallest flood which peaks at the lowest point of the non-overflow crest.

• These flood capability outcomes are used to create scatter plots of RRCR versus DCF. Lines of best fit are then drawn through the scatter plots and the associated regression equations are determined, thus producing the required reservoir flood capability prediction relationships.

The flood capability relationships which were developed using the above procedure (see Section 4.3, below for the results) form the main part of the overall design/review mechanism presented later in Section 5.

4.3. Developing the Flood Capability Prediction Relationships

Based on all six study catchment works discussed under Sections 4.1 and 4.2, a total of 130 hypothetical dam cases were created on the catchments so as to represent all the possible combinations of reservoir size and spillway capacity to pass the entire range of design floods up to the PMF. Flood capability studies were undertaken for each case in line with AR&R (IEAust, 1999, Book VI) and as described above. All cases resulted in an AEP of PMF of 1 in 10$^7$ using the new procedure in AR&R (IEAust, 1999): this therefore led to the Reservoir Catchment Ratio (RCR) taking on the compact form, ie. Equation 2.

The magnitude of the Dam Crest Flood (DCF) capability 1/AEP (years) was found to be a power function of the Reservoir Catchment Ratio for a single line of best fit over the entire range of AEPs. The sample data and line of best fit are presented in Figures 13 and 14 respectively.
The coefficient of determination ($R^2$) for the relationship presented in Figure 14 suggests a high level of predictive accuracy: this is a very positive result. However, applying the above relationship required also being able to accurately predict the peak PMF inflow associated with a dam for input to the RCR in order to establish the Regionalised Reservoir Catchment Ratio (RRCR). The peak PMF prediction equation for
the six study catchments based on “AR&R (1987) $k_c$” values is presented in Figure 15; also provided is a comparison with (1) the Nathan et al (1994) regression (see also Equation 3), (2) the regression obtained based on “calibrated $k_c$”, and (3) the regression obtained based on the $k_c$ derived using the Dyer et al (1994) procedure. The comparison in Figure 15 shows that for PMF prediction the “AR&R $k_c$” based regression provides the best coincidence with the Nathan et al (1994) regression: this is further evidence to support the use of the “in-between” AR&R method of determining $k_c$ for small catchments in Victoria such as those used for this project, as discussed previously under Section 4.2.2.

The above relationship displays a reasonable predictive accuracy. The equation was substituted into the RCR to produce the Regionalised Reservoir Catchment Ratio (RRCR) applicable to the sample region as follows:

$$ RCR = 130.19 \cdot CA^{0.4483} \cdot f\{SC, RA, SH, CA\} $$

(6)

The flood capability (DCF) outcomes for the six study catchments were again used to create a scatter plot of RRCR versus DCF, representing the entire State as illustrated in Figure 16. A new flood capability prediction relationship was constructed using the same sample outcomes and the resulting scatter plot and line of best fit representing the whole State is presented in Figure 17.
**Figure 16:** RRCR Sample Data According to each of the Study Regions

**Figure 17:** Sample Data and Line of Best Fit for DCF Prediction Based on the RRCR
Figure 17 demonstrates increased scatter and, hence, some loss of accuracy in moving from the RCR to the RRCR for the State curve; this being a direct result of using the derived PMF prediction equation. However, this loss in accuracy is by no means significant as an $R^2 = 0.87$ is still highly satisfactory. Nevertheless, the relationship in Figure 17 can be converted into more accurate regionalised sub-curves as was done for NSW and as presented in Figure 18.

![Figure 18: Flood Capability Prediction in the Form of More Accurate Regionalised Sub-curves: Victoria](image)

The coefficient of determination ($R^2$) for the relationships presented in Figure 18 are all better than 0.95 (ie 95%): this suggests an excellent (almost perfect) level of predictive accuracy. This means that any farm dam in Victoria can be assessed and/or designed with a high level of accuracy and confidence using these prediction relationships and input of the simple parameters described in Section 2.

The flood capability relationships presented above (Figures 17 and 18) form the main part of the overall design/review mechanism presented in Section 5. Section 5 well explains how the mechanism can be applied in either review or design mode, where review mode enables the spillway of any existing dam to be checked against modern best-practice safety criteria, while design mode enables the spillway and storage capacity to be either re-designed for an existing dam or designed for a new dam.
4.4. Relationship for Converting Flood Capability from 1/AEP to %PMF

In the flood capability studies undertaken for each case, DCF capability was also determined as %PMF (as done in NSW). These outcomes were plotted against DCF capability as 1/AEP (years) in order to establish the relationship presented in Figure 19. This relationship complements the relationships above (Figures 17 and 18) in that it provides the option of converting any flood capability (determined using the cost-effective process) from 1/AEP to “%PMF Inflow”. This is an important option to have as sometimes modern spillway safety criteria are based on the latter output (for example, the criteria used by the NSW Dams Safety Committee, see NSW DSC, 1993).

![Figure 19: Sample Data and Line of Best Fit for Conversion of DCF from 1/AEP to %PMF](image)

The coefficient of determination of the above relationship is close to unity. Therefore, the regression enables satisfactory conversion of flood capability from 1/AEP to %PMF.
5. Application and Discussion of the Developed Flood Capability Design/Review Procedure

The relationships presented in Sections 3 and 4 (ie. Figures 5, 6, 8, and 9 for NSW and Figures 17 and 18 for Victoria) provide a procedure to engineers and dam owners to readily and effectively review and/or design the spillway flood capability of reservoirs on small catchments: area up to 100 km\(^2\) in NSW and, say, 20 km\(^2\) in Victoria. ANCOLD (1986) criteria on design floods for dams, which for the most-part coincide with ANCOLD (2000) ‘fallback’ acceptable flood capacity criteria (see Table 3), can be incorporated into each of Figures 5, 6, 8, and 9 for NSW and Figures 17 and 18 for Victoria to create Figures 20, 21, 22 and 23 for NSW and Figures 24 and 25 for Victoria respectively: the principal design/review tool in the form of either a State curve or regional sub-curves. The relationship previously developed by Pisaniello (1997) for South Australia is presented in Appendix 5: this together with the relationships presented below, establishes a procedure applicable to Southeastern Australia.

The procedure can be used in either review or design mode. However, the following three main conditions are associated with the mechanism:

1. the catchment must be free of any significant flow attenuating storages upstream of the principal reservoir as these contribute to non-systematic, case-specific type flood response.
2. the spillway(s) must be free flowing and weir-type in nature.
3. the flood capability (ie: DCF) must be taken as the smallest flood which peaks at the lowest point of the non-overflow crest. Providing this conservative condition is acceptable, the mechanism can be applied to any dam-type structure. ANCOLD (1986) suggests that this condition is appropriate for embankment type dams.

<table>
<thead>
<tr>
<th>Incremental Flood Hazard Category</th>
<th>Annual Exceedance Probability</th>
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<tr>
<td>High</td>
<td>PMF to 1 in 10,000</td>
</tr>
<tr>
<td>Significant</td>
<td>1 in 10,000 to 1 in 1000</td>
</tr>
<tr>
<td>Low</td>
<td>1 in 1000 to 1 in 100</td>
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Table 3: ANCOLD (1986) and ANCOLD (2000) “Fallback” Recommended Design Flood Exceedance Probability Standards

The criteria used by ANCOLD for the three hazard categories in Table 3 can be summarised as follows:

- **High Hazard Potential** – dam failure will endanger many lives in a downstream community and will cause extensive damage
- **Significant Hazard Potential** - failure may endanger some lives and will cause extensive damage
- **Low Hazard Potential** - failure poses negligible risk to life and will cause limited damage

The acceptable flood capacity determined from Table 3 can be compared to the Dam Crest Flood (DCF) of an existing dam to determine whether its spillway flood capability is adequate.
Figure 20: NSW Reservoir Flood Capability Design/Review Relationship Incorporating ANCOLD (2000) Criteria: State Curve for Catchments between 25 km$^2$ to 100 km$^2$ (refer to Equation 4 for the RRCR)

Figure 21: NSW Reservoir Flood Capability Design/Review Relationship Incorporating ANCOLD (2000) Criteria: Regional Sub-curves for Catchments between 25 km$^2$ to 100 km$^2$ (refer to Equation 4 for the RRCR)
Figure 22: NSW Reservoir Flood Capability Design/Review Relationship Incorporating ANCOLD (2000) Criteria: State Curve for Catchments up to 25 km² (refer to Equation 5 for the RRCR)

Figure 23: NSW Reservoir Flood Capability Design/Review Relationship Incorporating ANCOLD (2000) Criteria: Regional Sub-curves for Catchments up to 25 km² (refer to Equation 5 for the RRCR)
Figure 24: Victoria Reservoir Flood Capability Design/Review Relationship Incorporating ANCOLD (2000) Criteria: State Curve for Catchments up to 20 km² (refer to Equation 6 for the RRCR)

Figure 25: Victoria Reservoir Flood Capability Design/Review Relationship Incorporating ANCOLD (2000) Criteria: Regional Sub-curves for Catchments up to 20 km² (refer to Equation 6 for the RRCR)
When using the procedure in review mode, the simple parameters required in the associated
dimensionless ratio (Equation 4 for NSW curves for catchments between 25 km$^2$ to 100 km$^2$; Equation 5
for NSW curves for catchments up to 25 km$^2$; and Equation 6 for the Victoria curves) must be first
determined for an existing reservoir. These parameters are then put into the prediction relationship to
read off the corresponding flood capability, which is automatically checked against the displayed
ANCOLD criteria. When used in design mode, the same basic parameters are related to a proposed
reservoir, or upgrade of an existing reservoir. The parameters must be varied iteratively in the associated
dimensionless ratio until the ANCOLD safety criteria together with the owner’s storage needs are
satisfied. Any proven method for estimating the storage capacity of a reservoir can be a useful tool in the
iteration process, but is not a critical one as it does not affect the predicted flood capability used for
design. Pisaniello (1997) developed a model for this purpose based on two equations:

$$ V = 0.415 A H $$  

(7)

$$ V(h) = \sqrt{\frac{A h^2}{2H} + \frac{A h^3}{3H^2}} $$  

(8)

where:

- $V =$ total storage volume
- $A =$ top surface area
- $H =$ maximum height of storage
- $h =$ any height less than the maximum height ($H$)
- $V(h) =$ storage volume at height ($h$)

This model was verified by Pisaniello (1997) against real storage-height relationships of South
Australian farm dams. In order for the model to be used with confidence in Victoria or NSW, it should
be verified against Victorian and NSW data sets. Nevertheless, the model can still be used as a rough
predictor of storage capacity for farm dams in these States.

It should be noted that while the regional sub-curves of Figures 21, 23 and 25 provide better predictive
accuracy than the State curves of Figures 20, 22 and 24, they are less credible: this is because the sub-
curves are each based on fewer catchments, whereas the State curve is based on more catchments
collectively. This unfortunately creates an indeterminable credibility/accuracy trade-off which can only
be addressed by future works as discussed in Section 6. Nevertheless, if the relationships are to be used
as they stand, it is suggested that values be derived from both the State curve and the regional sub-
curves: whilst it would be satisfactory to adopt the less conservative value in the review of an
existing dam, the more conservative result should be adopted in design.

If for any circumstance the flood capability of a reservoir is to be known in terms of %PMF, say for
example, to compare with the NSW Dam Safety Committee’s criteria (NSW DSC, 1993), then Figure 26
(equivalent to Figure 10), Figure 27 (equivalent to Figure 11) or Figure 28 (Equivalent to Figure 19) can
be used to make the conversion.
Figure 26: Relationship for Determining DCF Capability as %PMF for Reservoirs on Catchments between 25 km² to 100 km² in NSW (refer to Equation 4 for the RRCR).

Figure 27: Relationship for Determining DCF Capability as %PMF for Reservoirs on small Catchments up to 25 km² in NSW (refer to Equation 5 for the RRCR).
Figure 28: Relationship for Converting DCF Capability from 1/AEP to %PMF for Reservoirs on Small Catchments up to 20 km² in Victoria
6. Implications and Recommendations

Farm owners may be legally liable for the damages caused by their dam in the event of failure. Liability arises when farmers have not built their dam to an acceptable standard using the best advice and methods reasonably available. Farmers often overlook the need to properly review/design dams because of high engineering consulting costs: this leaves them vulnerable to litigation if their dam fails. “Failure” does not necessarily mean the same as “collapse” of the dam. For example, any inability to pass incoming flood waters via the spillway may be regarded as failure of the dam.

Legal Liability may arise under the Common Law of Negligence and/or under Legislation, for example, the NSW Dams Safety Act 1978 and the Victorian Water Act 1989. In NSW the Dams Safety Act is administered by the Dams Safety Committee which closely monitors the safety of significant dams. In Victoria the Water Act gives the Victorian Civil and Administrative Tribunal (VCAT) authority to hear complaints on common law claims for dam failure as well as claims brought under the Act itself. Under the Water Act all dams require a licence to ‘take and use’ water. At the same time, potentially hazardous dams require an operating licence that will contain conditions relating to surveillance and dam safety.

However, even if a dam does not require an operating licence, it is in the farmer’s best interest to ensure the dam is safe and well maintained otherwise the life of the asset could be severely diminished. The risk of owning a dam can be shared by having suitable insurance cover. However, the premium and/or validity of any claim may depend on the processes used to design and maintain the dam.

Therefore, there is a clear need to encourage landholders to review the spillway flood capabilities of their dams in line with current acceptable practice and to take appropriate remedial action where necessary. The cost-effective regionalised procedure developed here can be used to provide such encouragement. The procedure is applicable to dams on small catchments up to 100 km$^2$ in size in NSW and up to 20 km$^2$ in size in Victoria: this will usually cater for most private dam cases in each State.

The main benefit of the procedure is its simplicity which dramatically reduces the great effort and resource that is normally required for conducting a “state of the art” reservoir flood capability study. The procedure provides a basis for quick yet accurate review and/or design of private dam spillways against any design flood standards, and is in line with modern acceptable practice which is of critical importance in a court of law in the event of litigation.

However, at present the regional relationships upon which the procedure is based are not finalised, primarily because of the lack of representation of varying catchment sizes and locations throughout each State’s sub-regions. This will be addressed in the near future by an ARC Discovery project, which will further extend this research via a “community partnerships” approach. Nevertheless, as they stand, all relationships display excellent predictive accuracies, therefore enabling them to be used in practice with confidence.

With the availability of the procedure, landholders can now have their dams reviewed and/or re-designed to ensure they comply with modern acceptable standards, but at a fraction of what it would have previously cost. The procedure can be applied either in the checking of existing dams, the re-design of existing dams or the design of new structures. Both spillway and storage designs can be tailored to suit the surrounding landscape and the storage requirements of the landholder. Applying the procedure simply requires a short visit by an engineering practitioner in order to measure the necessary variables and parameters. The resulting design information is presented graphically, in a format that is easily understood by both landholders and construction contractors. Overall, applying the procedure helps landholders
preserve their asset longer, assists with any insurance cover, provides a form of insurance policy against liability and promotes better dam safety management.

The commercial potential of the cost-effective procedure is therefore obvious - it provides quality results but at an affordable price. This is especially significant in regions where spillway safety review is mandatory by legislation, and hence the demand for the procedure becomes somewhat assured. In Victoria alone there are some 800 farm dams which have been identified as requiring review. Therefore, the key details of the design/review relationships as developed in this “interim” study have been kept confidential in order to avoid any persons using the relationships and charging unreasonable fees before they are even finalised by the future ARC research. Once the relationships are finalised, various options will be assessed to how best ensure that the cost-effective benefits of the procedure are not abused, but rather passed on to the farming community. For example, licencing the procedure to a number of engineering firms and then relying on market forces to ensure that the savings are passed on, or perhaps establishing a new “farmer-friendly” company that will deliver the spillway service at a cost-effective price.

In the meantime, any landholders requiring the cost-effective service based on the “useable” procedure presented here can contact Dr John Pisaniello at the University of South Australia (ph: +61 8 8302 0031), and an interim review can be organised via the University’s “controlled” business services.

Bringing the curves together here from each of the three States, NSW, VIC and SA, has successfully established a mechanism applicable to the whole of Southeastern Australia. The project has gone a long way in establishing a scientifically acceptable procedure that will promote consistency and uniform standards and strongly encourage better private dam design and safety management in Southeastern Australia. This will set a precedent for the remaining States to follow so as to ultimately develop a mechanism applicable Australia-wide.
7. References


*Dams Safety Act 1978 (NSW)*

Dept of Natural Resources and Environment Victoria (2002), ‘Your Dam, Your Responsibility – A guide to managing the safety of farm dams’, The State Govt of Victoria, Australia.


*Water Act 1989 (Vic)*

Water Act 2000 (QLD)
Appendices

APPENDIX 1

MAIN REGIONS OF NSW AND STUDY CATCHMENT LOCATIONS
(in region groups, labelled 1, 2, 3…… in each region)
APPENDIX 2

STUDY CATCHMENT LOCATIONS IN VICTORIA
APPENDIX 3

Preliminary design/review relationships for Victoria developed as part of a previous DNRE pilot study (Pisanrello & McKay, 2000)

(based on AEP of PMF = 1 in $10^6$)
Figure 3.1: Sample Data and Line of Best Fit for IFF Prediction Based on the RRCR (AEP of PMF = 1 in $10^6$)

Figure 3.2: Some Additional Sample Data and Line of Best Fit for IFF Prediction Based on the Conservative RRCR and Comparison with Non-conservative Curve (AEP of PMF = 1 in $10^6$)
APPENDIX 4

PRELIMINARY DESIGN/REVIEW RELATIONSHIPS FOR VICTORIA BASED ON 3 GAUGED CATCHMENTS RE-DEVELOPED AS PART OF THE INITIAL STAGES OF THIS RIRDC STUDY

(based on AEP of PMF = 1 in $10^7$ and a complete data set for the sensitivity study)
Figure 4.1: Sample Data and Line of Best Fit for DCF Prediction Based on the RRCR (AEP of PMF = 1 in $10^7$)

Figure 4.2: Complete Sample Data and Line of Best Fit for DCF Prediction Based on the Conservative RRCR and Comparison with Non-conservative Curve (AEP of PMF = 1 in $10^7$)
APPENDIX 5

DESIGN/REVIEW RELATIONSHIPS FOR SOUTH AUSTRALIA
DEVELOPED BY PISANIELLO (1997)
Regionalised Reservoir Catchment Ratio (RRCR) = \frac{SC}{97.805 \cdot CA^{0.7747}} \cdot \sqrt{\frac{RA \cdot SH}{1000 \cdot CA}} \cdot \log \left( \frac{97.805 \cdot CA^{0.7747}}{5.2404 \cdot CA^{0.7453}} \right) \cdot \log \left( \frac{5.2404 \cdot CA^{0.7453}}{4.0985 \cdot CA^{0.7799}} \right)

where:
- SC = spillway overflow capacity (m³/s)
- CA = catchment area (km²)
- RA = reservoir area when Full (km²)
- SH = max. spillway overflow height (m)

Figure 5.1 Reservoir Flood Capability Design/Review Mechanism incorporating ANCOLD (2000) Criteria: South Australia (after Pisaniello, 1997).