Small dams safety issues – engineering/policy models and community responses from Australia

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Abstract

Dam safety is a serious issue worldwide. However, in many countries, for example, China and Australia, although much attention is being devoted to the medium to large-scale dams, little or no attention is being paid to the serious potential problems associated with smaller dams, particularly the potential “cumulative domino effect” failure risk to the larger public dams. Farmers in Australia have often overlooked the common law obligation to review/design dams in line with current standards because of high engineering consulting costs. This leaves them vulnerable to litigation if their dam fails and the downstream community is susceptible to unacceptable risk levels. To overcome this problem, an innovative Australian-developed cost-effective spillway design/review procedure has been developed to minimise cost burdens to dam owners and encourage better dam safety management. A recent survey undertaken in the Australian “policy model” State of Victoria to test community attitudes to the procedure and implemented dam safety and water allocation policy is also reported here. This survey clearly demonstrates that farmers require more than awareness and encouragement in order to ensure that they look after their dams properly.

Keywords: Australia; China; Community responses; Engineering flood model; Policy lessons; Small dams safety

1. Introduction

In the 20th century the use of dams multiplied rapidly to provide a range of benefits for people. At the same time, this increase has coincided with a number of horrific failures worldwide and triggered serious concerns over the safety of dams. For example, the failure of the Machhu II dam in India in 1979 resulted in over 2000 deaths, while the Canyon Lake and Buffalo Creek dam failures in the USA in 1972 resulted in over 2000 deaths, while the Canyon Lake and Buffalo Creek dam failures in the USA in 1972 resulted...
in 237 and 125 lives lost, respectively. Many countries have therefore found it necessary to adopt dam safety regulation and surveillance Acts in an attempt to ensure dam safety.

When existing dams were constructed, the majority more than 20 years ago, their designs could only be based on information, criteria and practices available and relevant at the time. However, many aspects have changed over time, such as population distributions, infrastructure patterns, meteorological information, engineering methods and design standards, together with the condition of the dams, raising serious doubts about dam adequacy. In particular, significant advances made in the fields of meteorology and flood hydrology have updated both maximum possible rainfalls and design flood levels from those on which most existing dams were based. As a result of these revisions, many dams have insufficient spillway capacities. This is an issue receiving much concern and attention worldwide.

While failures of large dams are generally more spectacular than those of smaller dams and receive much more attention, small dam failures, particularly those belonging to privately owned farm dams, occur far more frequently (Pisaniello, 1997; Lewis & Harrison, 2002). Therefore, in many cases, the total annual cost of small dam failures is more serious than the rare failures of large dams, especially in relation to government owned infrastructure. Also, past events have occurred where failures of relatively small dams have had quite disastrous consequences. In the United States for example: a 19 m high earth dam failed in Pennsylvania in 1889 leading to the destruction of Johnstown and killing of around 3,000 people, this being, in terms of lives lost, one of the largest disasters of all time in the USA (Sowers, 1974). The Kelly Barnes Lake dam, only 8 m high, failed in 1977 killing a total of 39 people and the Lake Lawn dam in Colorado which was also 8 m high and stored only 830 ML, failed in 1982 drowning three people and causing US$31 million in damage despite warnings and evacuation (Hiser & McDonald, 1989). In fact in the USA, President Carter paid attention to the issue following the failure of the Kelly Barnes Lake dam in his home State of Georgia by commissioning an inventory of dams with regard to safety issues. In the final report presented to Congress in May 1982, some 68,000 dams were identified (64,000 being non-federal dams) and 8,800 of these were deemed to be “high” hazard dams. Following inspection of all the high hazard dams, 2,900 were rated as unsafe and of these, 2,370 were unsafe because of inadequate spillway capacity (US Department of Interior, 1980). These past events suggest that without appropriate design, construction and maintenance, poorly managed small dams can cause significant human and property losses to the community.

Consequently, the recognition of risks associated with the dams has increased greatly. A need has therefore developed for owners to manage their dams appropriately 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 addition, as it is the role of government to protect the community, an associated need has also developed for government to provide appropriate policies which assure the community of owner participation and which protect them from unacceptable dam safety management practices. This paper provides guidance on how best to meet these needs, focusing on China as an example and using research undertaken in Australia in the context of the small dam safety problem.

2. Dam safety and the small dam problem in China

Dam safety is a serious issue in China. However, similar to Australia, much attention is being devoted to the medium to large-scale dams, but little or no attention is being paid to the serious potential
problems associated with smaller dams. This is demonstrated in the sub-sections below via a discussion of the records of dams in China, a look at China’s dam safety regulatory regime and the associated need to raise public awareness of the problems.

2.1 The records of dams in China

There were virtually no large-scale water projects in China before 1949. But in the ensuing years and especially in the years during and since the Great Leap Forward (1958–60), China has heavily promoted dam construction as part of a massive national campaign. In less than 40 years, all of China’s major rivers have been dammed.

Nowadays there are more than 84,000 reservoirs of various types, which include more than 400 large-sized reservoirs (each with a capacity over 100 million m$^3$) and more than 2700 middle-sized ones (each with a capacity between 100 million and 10 million m$^3$). The total number of large-sized or medium-sized reservoirs is more than 3,100 (including 110 reservoirs managed by the State Power Cooperation). The remaining 80,000 are small-sized ones, each with a capacity between 10 million and 100 thousand m$^3$ of capacity (Wang & Wang, 2003).

The 80,000 dams and reservoirs built over the past 40 years have played an important role in flood control, electricity generation and irrigation and have provided water for urban areas and industry. These achievements should not be underestimated, but dam construction, especially during and after the Great Leap Forward, also had disastrous consequences. At the time of the “Great Leap Forward”, water conservancy policy “gave primacy to the accumulation of water irrigation and gave only secondary consideration to drainage and flood control” (Fu & Qing, 1998). Leaders boldly approved projects to accumulate more water for irrigation without knowing whether they were feasible. Because of the limited investment and techniques, lack of scientific design and construction procedures, many dams are now found to be defective and dangerous with low flood control standards, poor construction quality or hidden structural problems (Fu & Qing 1998).

According to Fu & Qing (1998), by 1973, 40% (or 4,501) of the 10,000 Chinese reservoirs with capacities between 10,000 and one million m$^3$ were found to have been built below project specifications and were unable to control floods effectively. Even more dams had problems relating to the geology of the dam site and to sedimentation. Most serious, however, were the numerous dam collapses. By 1980, 2,796 dams had collapsed, including two large-scale dams (the Shimantan and Banqiao dams). One hundred and seventeen medium-sized and 2,263 small dams had also collapsed. On average, China witnessed 110 collapses per year, with the worst year being 1973, when 554 dams collapsed. The official death toll resulting from dam failures came to 9,937 (not including the Banqiao and Shimantan collapses, which had a combined estimated death toll of up to 230,000). Some people say that among the more than 2,000 dam collapses, only 181 involved fatalities but this hardly seems accurate.

By 1981, the number of formally recognized dam collapses had risen to 3,200 – roughly 3.7% of all dams in China. According to Ma Shoulong, the chief engineer of the Water Resources Bureau of Henan Province, “The crap from that era [the Great Leap Forward] has not yet been cleaned up”. Many of the dams which remain are unsafe and in need for repair. It would appear that the “crap” left by the Great and Small Leaps Forward will linger for some time to come (Fu & Qing, 1998).

Meanwhile, it should be realised that the above-mentioned dams that were built in the two peak periods have already been operating for 30 to 40 years and some even for almost half a century.
The growing deterioration with dam age, lack of proper maintenance and poor quality of the dam has resulted in serious safety problems. Using incomplete statistics, 42% of larger-sized dams, 41% of medium-sized dams and 36% of small-sized dams are defective. Therefore, it will be quite an arduous task to rehabilitate and maintain these dams.

As regards large and important medium-sized reservoirs, their safety evaluation techniques have been given in relevant specifications, but as for small reservoirs, they are only required to refer to the relevant specifications in principle. However, in China, small dams are characterised by having no design, construction and operation management data and in a large number. Even a county, poor in economy, has about 100 small reservoirs, which cannot be operated in accordance with the requirement of the specifications for large and medium-sized reservoirs. In fact, evaluating small reservoirs is a complex technical problem. However, while there is no fundamental technical data, with the help of some experienced experts of dam engineering, it is easy to evaluate the existing problems for small dams. At present, evaluation of small dams is performed by county design units, which are not able to correctly judge dam defects, resulting in a direct influence on dam modification and rehabilitation schemes. Such a large number of small dams are indeed evaluated by the county design units, which, however, should be helped by experienced experts.

In China, there are rich experiences and techniques, but they are only suitable for large and important medium-sized dams. There have been no studies on the problems and key techniques for small dams (Li & Lu, 2003). It is difficult to predict the disasters that these dams might produce should they fail, because most information regarding dam collapses in China is confidential. According to experts, if the riskiest of these dams were to fail, hundreds of thousands of people could be killed. But current levels of funding are woefully inadequate to repair or reinforce the dams. At least ¥5 billion would be required for the large and medium sized reservoirs alone. Where will the money come from?

2.2 A need for regulatory separation in China

In China, dams-related projects are constructed and managed by government authorities. Conventional wisdom assumed that only the state was capable of handling large projects requiring heavy capital investment, complicated technical inputs and the legal mandate to distribute water and collect fees. This government-dominated approach may be referred to as supply-oriented management. Under this approach, the government agency supplies not only the water, but also the system managers and the operating rules.

China’s dam management adopts the system of level-by-level responsibilities, ranging from the authorities at national level to the authorities at grassroots level. Management can, by and large, be broken down into government administration, property management and operational management. Management organisations may be classified into administrative authorities, owners and operational management institutions (Zhou, 2003).

It is evident that governmental management style cannot work well enough, resulting in heavy cost burdens to both farmers and government, little attention paid to small dams and scant awareness of the risks posed by dams in communities. A regulatory separation from government is indeed required. However, Mark et al. (1997) argued that a sharp reduction in personnel and staff and change in the role of governmental agency with regard to dam management could encounter difficulties as follows:
“Once the government’s employees perceive the possibility of losing their jobs as a consequence of regulatory separation implementation, they may attempt to block the turnover process. Clear legal arrangements between the parties are needed in order to overcome difficulties. Unfortunately, as the number of people involved in the process may be quite large, this must be a painful process. The change requires not only willingness from the high-level officials but also training for them on specific issues. Once the turnover thoroughly takes place in a system, the agency’s new role should be more oriented towards supervision, guidance, monitoring and regulation of dams, plus selected technical assistance support to farmers. Management responsibility should be in the hands of users, with the possible exception of headwork which when considered of strategic importance or technically sophisticated, should remain under agency’s direct control and administration.” (Mark et al., 1997)

2.3 Some regulatory laws and rules related to dam safety management in China

Prior to 1978, there were no dam safety laws or regulations in China. Water administrative departments at different levels were responsible for dam safety. Manual for Observation of Hydraulic Structures is the only one published technical reference book (Wang & Wang, 2003). Since 1978, a series of regulations and technical criteria have been issued owing to recognition by government at all levels (Wang & Wang, 2003).

Since the 1980s, some regulatory documents and technical standards have been introduced one after another, such as Methods of Data Compilation for Earth-rockfill Dam Safety Monitoring (Ministry of Water Resources and Power, 1980), Technical Criteria on Concrete Dam Safety Works (Ministry of Water Resources and Energy, 1989), Safety Assessment Methods for Reservoirs and Dams (Ministry of Water Resources, 1995) and Safety Management Rules for Reservoirs and Dams (State Council, 1991). The Dam Safety Management Centre of the Ministry of Water Resources was established in 1988 and is responsible for organising and guiding the safety monitoring of dams in China and the compilation and analysis of relevant data. One more important leap which China had achieved was the enaction of Water Law, 1988 (by the National People’s Congress, 1988). Since Water Law 1988 was enacted, further laws were issued, such as Law for Water Pollution Prevention and Cure (National People’s Congress, 1996), Law for Flood-controlling (National People’s Congress, 1997), Law for Bidding (National People’s Congress, 1999) and Regulations for Quality Management (Ministry of Construction, 2000). However, most of these works focused on large and medium-sized dams. Safety management of small reservoirs is the weakest part of the current flood prevention system in China. The average defective ratio for small dams is much higher than for large and medium ones. Fortunately, officials and environmental groups gradually realised the dangers and planned to deal with them. More attention to dam safety management appeared in China’s new Water Law Act, which was enacted in October, 2002 (by the National People’s Congress, 2002) via the following two articles.

Article 42—The local governments at and above the county level should take measures to protect the water infrastructures within their respective administrative regions, especially the safety of dams and reservoirs, and eliminate the dangers associated with them within a time limit. The water administrative departments should reinforce the supervision and management of the safety of water infrastructure projects.
Article 43—The nation implements protection of water infrastructures. All nationwide water infrastructures should be divided clearly into safety management and supervision scopes according to the regulations of the State Council.

Today, new issues have arisen in the water resources field in addition to construction and management of dams. An example of one of these issues is discussed in Section 2.4, below.

2.4 The need to raise the public awareness

For a long historical period, the general public have not been involved in or informed of any decision-making process until the last minute in China. The people affected are usually informed just before they are going to be affected or will be resettled and they do not have a say in whether a proposed project should move forward, as the decision has already been made. In general, governments do not inform downstream communities about the quantities and timing of water releases from dams. This has caused serious droughts, floods and overall agricultural losses in many cases.

The people who suffer the most from drought or floods can only file complaints to their local governments and hope that the officials adequately reflect the situation to the provincial governments. This kind of bureaucratic procedure normally takes time and is not effective in changing the existing conditions of dam management problems (Li, 2003).

Since China gradually became more open to the world, there was an increase in people receiving a higher education and learned concepts from western countries. The economic growth rate remained at a high level, starting from over 10% and was then controlled by the central government at around 8%. While witnessing the changes brought by such rapid economic growth, Chinese people became more aware of their own environmental conditions.

People understood and began to address the environmental degradation issue but there is still need for massive assistance from foreign countries. Discussions, complaints and debates on environmental issues are ongoing in cyberspace and in the mass media.

With this general increase in environmental awareness among the public, environmental groups formed by journalists, academics, students and other concerned citizens have found that information disclosure is the key to affecting the decision-making process of hydropower development. They found that people generally have misconceptions about the positive side of development, without considering the negative impact.

Developing a strong grassroots movement that can influence government policy is still a long way away in China. While the downstream-concerned citizens do not know how to campaign at the grassroots level, they can try to adjust their expectations from their Chinese counterparts to enable more opportunities to learn from each other. This will take time and effort but will be worthwhile in the end. Meanwhile, experiences from other countries, such as those from Australia presented below, can serve to provide valuable lessons for all involved, including policy makers, dam owners and builders and the downstream community.

3. The significance of the small dam safety problem as experienced in Australia

In Australia, a clear problem with private dam safety has been identified (Pisaniello, 1997), that is, Australia has a large number of relatively small, privately owned dams (farm dams in particular) and
thousands of these that have failed. There are an estimated 480,000 farm dams scattered throughout Australia, costing approximately AU$50 million each year to build and maintain (Price et al., 2003). 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 fail (ANCOLD, 1992; Murley, 1987); at least ten significant failures have occurred in Victoria in the last decade (Lewis & Harrison, 2002), while ANCOLD (1992) report that the failure rate of farm dams in NSW is 23%. One of the main concerns is that most 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.

Research has shown that overtopping as a result of inadequate spillway capacity is one of the main causes of dam failure, representing approximately 40% of all recorded failures worldwide. Furthermore, embankment dams are most vulnerable to failure by overtopping, representing 70% of cases where dams have failed under flood (ANCOLD, 1995). This is of particular relevance to small dams, as the majority of these dams are of embankment-type construction.

Hence, owners should review the spillway flood capabilities of their dams and upgrade if necessary, in order to avoid liability for possible failure consequences (McKay & 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, private owners tend to neglect 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. Section 5 provides a workable solution to this problem as developed in Australia, but is transferable worldwide.

Another concern is that since most private dams are relatively small in size, they seemingly represent a “low” hazard to their immediate downstream inundation area and hence, the community accepts them designed to the lowest standard. Unfortunately however, when these dams are considered commutatively in a large catchment of, say, a large, highly hazardous public reservoir, then they each represent quite a significant incremental flood hazard as their cumulative failure can increase significantly the risk of failure (via the “domino effect”) of the public reservoir downstream. The effect of additional flooding in the connecting river systems can also be severe. This was demonstrated in a recent flood study of the Kangaroo Creek Dam in the Torrens catchment of South Australia (Lange Dames Campbell & Snowy Mountains Engineering Corporation, 1995), which recognised the need for “controlling the standard of construction of farm dams and their spillways”.

In effect, the recognition of risks associated with the dams has increased greatly. However at the same time more farm dams have been built to capture water since changes to the water allocation policies in Australia have been mooted since the early 1990s (McKay, 2001). A need has therefore developed for private dams and risk to co-exist and for owners to manage their dams appropriately 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 addition, as it is the role of government to protect the community, an associated need has also developed for government to provide appropriate policies which assure the community of owner participation and which protect them from unacceptable dam safety management practices. Unfortunately, dam safety legislation is often considered too “extreme” and alternative action is proposed but rarely follows. This is often largely because of overwhelming concern that legislation may place significant cost burdens upon both government and private owners to administer and conform with it respectively and there are no systematic guidelines on determining the
level of assurance policy that is “appropriate” for varying circumstances. Sections 4 below provides an example “model” state of how to best address these concerns.

4. Victoria: an example state on how to best address the small dam safety problem

Victoria is the only mainland Australian State to acknowledge and address the problem of generally low/significant hazard, off-stream farm dams. It has addressed farm dam safety by first recognising that it is a problem (together with the recent issue of equitable water allocation and capacity sharing) and then “partnering” the farming and downstream community to execute the law reform process. A Farm Dams Irrigation Review Committee was established in early 2000 and a discussion paper Sustainable Water Resources Management and Farm Dams was later released seeking submissions from the community. The paper addressed capacity sharing issues for off-stream dams and also recommended that potentially hazardous dams be regulated! From the responses received, over 70% were in favour of regulating potentially hazardous dams (Victoria State Government, 2001).

As a result of the reform, farm owners in Victoria may be legally liable for the damage 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 properly to 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 Water Act 1989 or the Common Law of Negligence. The Water Act gives the Victorian Civil and Administrative Tribunal (VCAT) authority to hear complaints about 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. Under s71, licence conditions include dam safety requirements such as 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 (Department of Natural Resources and Environment (DNRE) Victoria, 2002).

A further significant step in Victoria has been the publication of the booklet Your Dam, Your Responsibility – A guide to managing the safety of farm dams (DNRE Victoria, 2002). This targets the smaller yet hazardous dams which are usually ignored in most jurisdictions and educates dam owners on their responsibilities and potential liabilities. At the same time, the publication also educates the multitudes of non-hazardous dam owners, advising that 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 publication informs in simple language and illustrates the processes necessary to keep any farm dam in good safe condition. It provides a template dam safety emergency plan that is simple to understand and comply with. It also advises that the risk of owning a dam can be shared by having suitable insurance cover, but that the premium and/or validity of any claim may depend on the processes used to design and maintain the dam.

Finally, in order to address the problem of possibly placing unreasonable cost burdens upon the farming community, the Victoria Government recently commissioned the University of South Australia
to develop a cost-effective flood safety engineering procedure for the state as described in Section 5 below.

This integrated engineering and “community partnerships” approach to small dam safety adopted in Victoria should serve as an excellent example for other jurisdictions to follow.

5. A cost-effective regional flood safety design/review procedure

In order to encourage private dam owners to review and upgrade their spillways to meet current acceptable standards, a simple and cost-effective regional flood capability design/review procedure has been developed which 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.

The Pisaniello (1997) procedure primarily involves the development of regional flood capability prediction relationships for dams on small rural catchments based on the reservoir catchment ratio (RCR):

$$RCR = \frac{SC}{PI_{PMF}} \sqrt{\frac{RA \cdot SH}{1000 \cdot CA}} \frac{\log\left(\frac{PI_{PMF}}{PI_{100}}\right)}{\log\left(\frac{PI_{100}}{PI_{50}}\right)}$$

where SC is the spillway overflow capacity (m³/s), PI_{PMF} is the peak inflow for the probable maximum flood (PMF) event (m³/s), RA is the reservoir area at full supply level (km²), SH is the maximum height of spillway overflow (m), CA is the catchment area (km²), PI_{100} is the peak inflow for the 100 year design flood event (m³/s) and PI_{50} is the peak inflow for the 50 year design flood event (m³/s).

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 1 and in turn, the regionalised reservoir catchment ratio (RRCR), see Figure 1. Establishing the RRCR from the RCR for a region necessitates the formulation of “peak flow versus catchment area” prediction relationships for the 1 in 50, 1 in 100 and PMF events and substituting them into the RCR. The mechanism upon which the procedure is based involves using regionalised relationships based on simple hydrological/hydraulic variables to predict reservoir flood capability as either 1/AEP or percentage PMF: the former case for South Australia is illustrated in Figure 1. ANCOLD (1986) criteria on design floods for dams, which for the most part coincide with ANCOLD (2000) “fallback” acceptable flood capacity criteria (see Table 1), have been incorporated into Figure 1 to establish the principal design/review tool.

The acceptable flood capacity determined from Table 1 can be compared to the actual imminent failure flood (IFF) capability of an existing dam (obtained from Figure 1) to determine whether its spillway is adequate. If the spillway is not adequate, the process can then be applied in reverse, i.e. “design mode”, to determine an appropriate size spillway. It should be noted that ANCOLD (2000) now refers to IFF as dam crest flood (DCF).

The cost-effective procedure is applicable to reservoirs on small rural-type catchments (up to around 100 km²), is compatible with any design flood standards and is based on easily derived variables only (i.e. spillway width and height, reservoir area, catchment area), deeming it quick to use yet accurate in
The output it provides. **Figure 2** demonstrates the simple application of the procedure in both review and design modes.

The systematic process for transferring the procedure to any other region was developed as part of the Pisaniello (1997) PhD studies. The procedure was recently transferred successfully to the Australian states of NSW and Victoria in research projects funded by the Australian Research Council (ARC), the Rural Industries Research and Development Corporation (RIRDC), the NSW Department of Land and Water Conservation and the Victorian Department of Natural Resources and Environment. Further details of this are provided in Pisaniello & McKay (2003).

The main benefit of the mechanism is its simplicity, which dramatically reduces the great effort and resources that are normally required for conducting a state-of-the-art reservoir flood capability evaluation and/or design. For example, the consultant fee for undertaking such an evaluation and/or design for an embankment dam on a relatively small catchment is normally around AU$10,000.

Fig. 1. Reservoir flood capability design/review mechanism incorporating **ANCOLD (1986 and 2000)** criteria: South Australia (after Pisaniello, 1997).
The cost-effective procedure has the potential to reduce this fee to around AU$200. This fee is nominal when also compared to the actual dam construction cost of around $1000 per ML (Boehm, 2002). At the same time, the procedure is in line with modern best practice, which is very important for avoiding negligent liability in a court of law in the event of spillway failure and subsequent litigation. This:

- encourages all private dam owners to provide for a flood capability review of their dams on their own initiative which is important in states where dam safety assurance policy is either absent or of low level (for example, SA). This is also important for the many owners of small, low hazard dams as they are provided with an affordable means of preserving their asset against the high incidence of flood failure. The risk of failure of public reservoirs caused by cumulative failure of small dams is also reduced;
- encourages the “proper” flood design of all new private dams which in the case of most farm dams, is otherwise normally left to construction contractors who lack the expertise to provide satisfactory service in this area;
- provides law makers with a cost-effective mechanism for exploring and resolving the private dam safety problems in any region via the policy models and selection guidelines outlined by Pisaniello & McKay (1998);
- addresses the concern of government that an adequate private dam safety assurance policy may place unacceptably high cost burdens on rural communities. The procedure provides for high level assurance but via the simple and easily implemented “owner education and guidance” policy option. This therefore also provides cost savings to government in meeting its role to protect the community in the policy implementation process;
- assists dam owners in meeting conditions relating to surveillance and dam safety of any operating licence required under legislation, for example, the Water Act 1989 in Victoria and
- has the potential to provide assistance in minimising insurance premiums and validating claims.

Overall, applying the cost-effective flood safety procedure helps dam owners preserve their asset longer, assists with any insurance cover, provides a form of insurance policy against liability and promotes better, more uniform dam safety management.

6. Community attitude surveys in Victoria

The University of South Australia has recently undertaken a community attitude survey of 77 farmers owning a total of 140 farm dams in Victoria to test their response to the recent law reforms regarding farm dams, water allocation policy and this also included information on the cost-effective spillway design/review technology (discussed in Section 5, above). A list of 417 farmers owning dams for the
Cost-effective Flood Safety Procedure: Worked Examples

**Review Mode—Simplified Case Description:** Farmer Ron Jones owns a 200 ML embankment dam in Mount Lofty, South Australia with a catchment area of 2 km² (as measured from 1:25,000 scale topographical maps) and a well populated valley downstream in which would be a floodplain inundation area. The reservoir has a maximum still-water depth of 10 m and a surface area when full of 0.048 km² (as measured from 1:10,000 scale aerial photo). The dam has a free flowing, broad crested weir-type spillway which is 1m high (max.) to the lowest point on the non-overflow crest and 15m wide. Mr Jones would like to know if the flood capability of his dam is of adequate standard in relation to current ANCOFL flood guidelines?

**Review Mode—Simplified Case Solution:** The dam warrants a "A" hazard rating given the populated valley downstream (ANCOFL Flood Capacity Guidelines, 2000), it must therefore have an Inundation Failure Flood (IFF) capability of at least 1 in 10,000 years (AFIP) in order to be of adequate "ANCOFL" standard (see Table 1). This can be checked as follows:

- **Determine ROCR using Figure 1:**
  - RA = 0.048 km², CA = 2 km², SII = 1m,
  - Need to determine Spillway Capacity (SC) for which a rectangular weir with flow width, SW (m), and weir coefficient, Ce, is given by SC = CeSWH², where Ce = 1.69 for a free flowing, broad crested rectangular weir spillway (Hill, 1987; Pisaniello, 1997). Hence, with SW = 15 m and SII = 1 m, SC = 1.69 x 15 x 1.5 = 25.4 m³/s.
  - Substituting into the ROCR Equation in Figure 1:
    - ROCR = 0.021
  - Using the appropriate IFF prediction equation in Figure 1:
    - IFF = 36518.0 x 0.021 = 390 years (U/AFIP)
    - Hence, since 3900 is less than 10,000, the flood capability of the dam is of adequate standard and the dam requires remedial action! The necessary action can be determined using Figure 1 in design mode, as described below.

**Design Mode—Simplified Case Description:** Mr Jones, the owner of the dam in the above case, would like to know the amount by which he must increase the size of his spillway in order to make the dam of adequate flood capacity standard? However, he must be left with a full storage capacity of at least 190 ML in order to meet his annual farming needs, and he would also like to avoid the option of raising the entire non-overflow crest.

**Design Mode—Simplified Case Solution:** A new spillway can be designed as follows:

1) In the review of this dam, 1 in 10,000 AFIP for the Recommended Design Flood (RDF) was used as the minimum "acceptable" standard (see Table 1). To design, apply Figure 1 in reverse, but increase the RDF by a small factor of safety of, say, 4% as follows:

- Introduce a 4% factor of safety by increasing the minimum required IFF standard (ie IFF) by this magnitude;
- RDF = antilog(1.04 x log10(10,000)) = 14500 years (U/AFIP)
- Thus, can determine the "required" ROCR to meet this standard by using the appropriate equation in Figure 1 in reverse;
- For 14500 = 3 x 10²/IFFCR², ROCR = 0.064

2) Can now design the new spillway for ROCR = 0.064 by using the ROCR Equation in Figure 1 in reverse:

- As the height of the spillway (SH) cannot be increased by raising the embankment, extra spillway capacity can only be obtained by widening the spillway (either the existing one or a new secondary one) and/ or deepening its base. However, the amount by which the bottom of the spillway can be deepened is restricted by the farmer’s storage capacity requirement. Therefore, need to determine the maximum depth that the spillway can be dug out without losing excessive storage capacity. This can be done by "trial and error" as follows:

- Try increasing spillway depth by 0.2m, ie: SH = 1.2m. Therefore, the maximum reservoir depth reduces from 10m to 9.8m, and the total storage capacity reduces from 200 ML (by approximately 0.048 x 10² x 0.2 = 9600 KL = 9.6 ML) to 190.4 ML.
  - At 190.4 = 190, increasing the depth of the spillway by 0.2m is just acceptable. Therefore, can work with SH = 1.2 m new maximum spillway depth.
  - Also, reducing the still water depth of the reservoir by 0.2 m will reduce the reservoir area at full supply level (RA) by approx. 0.2 / 10 = 2%. This therefore gives a new RA = 0.047 km².
- Therefore, substituting all necessary parameters into the ROCR Equation in Figure 1 and applying it in reverse;

    \[
    0.054 = \frac{SC}{98.705 + 2.657} \sqrt{0.047 - 1.2} \left( \log \frac{5.2496 - 4.2696}{4.0985 - 2.657} \right) \]
    \[
    SC = 98.7 m³/s
    \]

- The spillway width (SW) required to provide this spillway capacity for a 1.2m maximum depth is determined using the broad-crested rectangular weir equation (presented above under Review Mode) in reverse;

- For 397.9 = 1.69 x SW x 1.2²

  \[
  SW = 26.9 m, \text{ say 27m.}
  \]
- Therefore, as the spillway width is already 15m, it must be increased by 12m for a 0.2m increase in depth.

**Overall Assessment:** The size of the spillway must be increased from 1m deep x 15m wide to 1.2m deep x 27m wide in order to satisfy the current ANCOFL flood capacity standard.

Fig. 2. Review and design mode worked examples demonstrating the application of the cost-effective flood safety procedure (after Pisaniello, 1997).
purpose of grape growing were targeted in the survey. The grape growing industry was selected because of its tendency to require the more larger-sized, significant type farm dams. After an initial telephone call and invitation to participate in the survey, approximately 120 of the 417 agreed to have the relevant information (i.e. an information brochure) sent to them and to be called back for interview. Following the call-backs to these 120 participants, only 77 agreed to participate further in the actual questionnaire. Those who refused to participate further gave reasons such as (1) being too busy, (2) they felt that they had already been questioned too much in previous government surveys and questionnaires and (3) they felt the survey was not relevant to their dams and they knew nothing about the new laws.

The telephone interview questionnaire was around 25 minutes in length and attempted to test the farmers’ attitude towards a number of aspects including:

- Is water shared fairly?
- Is there communication with neighbours about dam safety?
- Are they willing to join a Water Allocation and Management Plan (WAMP)?
- What is their attitude towards the Victoria water authorities?
- How safe is the dam?
- What amount are they willing to spend on dam safety per year?
- What is their reaction to the cost-effective flood safety procedure?

From analysis of the survey results: (1) 50% of farmers agreed that water is shared fairly in their neighbourhood, while another 35% neither agreed or disagreed, (2) only 22% of participants talked to their neighbours about the capture of runoff in their dams, (3) 82% of the farmers had not participated in the development of a water allocation plan and of those, only 48% were willing to participate in the water allocation planning process, (4) only 17% of participants trusted their water authority, (5) almost 100% of participants believed that their dam(s) is safe, (6) 62% of participants currently spend nothing on maintaining their dam(s) per year and 81% of these intend to continue spending nothing per year to maintain their spillway(s) and (7) only 22% gave positive feedback towards the cost-effective spillway safety technology and indicated a willingness to take advantage of it in some way in the future.

The above results indicate that the law reforms in Victoria have made some inroads in achieving fairer water allocation/sharing and better dam safety in the state. However, more work is clearly needed to encourage farmers to talk to their neighbours, to develop a trust in their water authority and to participate in the water allocation planning process. Most importantly, more effort is needed to raise farmer awareness of dam safety issues, as most seem to have developed the complacent attitude that since the dam has not failed up to now, then it will never fail. This is indicated by the overwhelming number of participants who believe their dams are safe, while not spending any money to maintain them each year and not willing even to check the situation despite the availability of affordable spillway design/review technology. This shows that efficient and effective administration of the laws is vital.

7. Conclusions

China, as like most other countries worldwide, has in place many important components of a good dam safety structure when it comes to medium to large size dams. In particular, China should keep its national regulation, and the Water Law in the People’s Republic of China enacted in 1998 is an excellent idea. Despite the movement and development of a “social market economy”, it would be wise to
preserve this national approach. In other market economies like Australia national laws are seen as
enhancing the security of the society by ensuring that environmental risk is relatively uniform between
citizens in different areas. Indeed national regulation of water has been adopted in other countries as a
great leap forward, such as in Brazil and South Africa.

However, China and all other nations, should also recognise that the small dam safety problem can be
significant and therefore should check and/or address the extent of this problem within their borders via
an integrated engineering and community partnerships approach similar to that being implemented in
Victoria. Establishment of cost-effective flood safety technology would also serve as a very useful tool
for all small dam owners and builders in a country. The technology clearly promotes consistency and
uniform standards in small dam flood design. Hence, given this and the numerous other benefits that the
technology delivers, the Chinese government, for example, should be encouraged to establish it in China
and, in turn, promote it in all the necessary regions.

Overall, the Australian experience discussed here can provide China as well as other nations with a basis
for establishing properly organised and systematic small dam safety assurance programmes which are
effective in minimising cost burdens on both dam owners and government and the risks faced by downstream
communities. This will indeed provide a deserved level of safety assurance for all concerned and promote the
ideals of reducing loss of life as well as economic and environmental losses. However, adequate assurance
can only be provided through the implementation of appropriate policy, which requires the backing of law
makers. Effective and efficient administration of laws is also vital. The results of the survey reported here and
the “model” approach suggested should encourage such backing and efficiency.

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