# USING MAJOR WATER SUPPLY DAMS FOR FLOOD MITIGATION AND THE POTENTIAL IMPACTS DOWNSTREAM

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## Abstract

There is significant community interest in the potential for water supply dams to be adapted for flood mitigation, particularly for major dams located upstream of flood vulnerable populations. There may be a number of large dams which have the potential to provide significant flood mitigation benefits to Australian communities if they can be adapted for flood mitigation functionality. Other dams already provide significant flood mitigation benefits, however their limitations are not properly understood by the general public. Two major dams located near a large urban town centre prone to flooding are examined as a case study and some international cases are presented.

Flood mitigation often has a different funding source to water supply. The funding arrangements for flood mitigation dam works can be complex, considering the potential stakeholders and somewhat intangible benefits. If the community wants to use a water supply dam to provide flood mitigation then what options are available, how does this interact with other flood mitigation measures such as downstream levees and who provides the funding if structural modifications are required.

## Introduction

As defined by BTRE (2002), the purpose of flood mitigation is to decrease or eliminate the impact of floods on society and the environment. It is generally not possible to eliminate the potential for flood damage to certain communities located in flood vulnerable locations, however it can be possible to significantly reduce the risk of damage with flood mitigation dams. Flood mitigation is not limited to dams and can include other structural measures as well as non-structural measures such as property modifications and response modifications. The focus of this paper is, however, on the use of major dams for flood mitigation in Australia.

A large dam is defined by ANCOLD (2012) as one which is:

a) more than 15 metres in height measured from the lowest point of the general foundations to the crest of the dam,

b) more than 10 metres in height measured from the lowest point of the general foundations to the crest of the dam, provided they comply with at least one of the following conditions:

   i. the crest is not less than 500 metres in length

   ii. the capacity of the reservoir formed by the dam is not less than 1 million cubic metres

iii. the maximum flood discharge dealt with by the dam is not less than 2000 cubic metres per second

iv. the dam is of unusual design

VICSES (2013) outlines that the degree of flood mitigation a dam can provide depends on a number of factors including:

- the operating rules of the storage
- the size of the flood event
- the catchment size
- the level of water in the dam at the beginning of the event
- the capacity of the reservoir to store floodwaters above its full supply level
- the area of uncontrolled catchment downstream of the dam
- the discharge capacity of the spillway

Most dams across Australia have been constructed as water supply storages, with very few dams intended for flood mitigation purposes. As outlined by MDBA (2013), many water supply dams are managed/operated to meet the following objectives, in priority order:

1. Protect the structural integrity and safety of the dam; then
2. Maximise water availability; and then
3. Limit flood damage to downstream communities and increase benefits to the environment and public amenity.

The costs associated with water supply dams are covered by the supply of water to communities, whilst dam works associated with the provision of flood mitigation involve very complex funding arrangement considerations. If the community wants to use a water supply dam to provide flood mitigation then who provides the funding for the modification works? While water supply may benefit the whole community in a region, the benefits of flood mitigation are usually confined to a small portion of the community.

The 2011 Brisbane floods, and particularly the role of Wivenhoe Dam (Figure 2) and Somerset Dams as partial flood mitigation storages, have been a major discussion point within the Brisbane community and throughout Australia in recent times. The devastating impacts of the 2011 Brisbane floods have sparked significant interest in the function of water supply dams for the provision of flood mitigation benefits to the community, particularly for those dams which are located near populations at risk of flooding.

This paper will explore the options available for adapting water supply dams into dual purpose storages with both water supply and flood mitigation functionality, along with the complex stakeholder funding arrangements for such projects. Some international cases will also be examined.

Additionally, the interaction between flood mitigation measures within a region's flood risk management system will be examined and the importance of detailed whole of system assessments, when changes to the system are proposed, will be outlined.

## Methodology

All dams provide some form of flood mitigation as rainfall inflows are stored within the freeboard of the dam before overflowing through the spillway, however dams designed as water supply storages generally do not provide any significant level of control over flood releases.

There are very few large dams in Australia which have been constructed purely for flood mitigation aside from small detention basins which are typically used to mitigate floods in urban catchments.

In terms of flood mitigation functionality, dams typically fall within three categories:

1. Water supply and flood mitigation – designed for dual function (Refer to Case Study 1 below).
2. Water supply dam operated/modified to provide flood mitigation function (Refer to Case Study 2 below).
3. Water supply only - incidental flood mitigation function.

This paper focuses on category 1 and 2 dams as listed above, with particular attention to the adaptation of existing water supply dams into dual purpose water supply and flood mitigation storages.

There are numerous methods to adapt a water supply dam for flood mitigation, with the most common being:

- pre-releases well in advance of a flood event and/or alternative gate operational rules during flooding events (if applicable)
- permanent lowering of the full supply level (FSL)
- physical modification of the dam to provide additional temporary storage.

When assessing the possibility of adapting a water supply dam for flood mitigation a range of options must be considered. The advantages and disadvantages of each of the options must be evaluated and assessed on a value-benefit basis with focus on the effect on downstream communities. The following will examine in more detail the options available to dam owners.

***Pre-releases – creating temporary airspace for flood mitigation***

Pre-releases (releasing water prior to the ‘wet season’ or well before an expected flood event to create airspace within the dam to ‘absorb’ or capture the first of the floodwaters) is feasible for some dams but typically provides only minor incremental flood mitigation benefits when only a small loss of storage volume is acceptable to the dam owner. The time between the rainfall occurring in the upstream catchment of a dam and the dam filling and spilling provides only a limited time for releases to be made. This approach has other issues including the potential for the public to criticise the operation scheme employed by the dam owner, as was seen with Wivenhoe Dam during the 2011 Brisbane floods.

Dam owners can find themselves in a situation where if they release water too early and the expected flooding does not eventuate then they are accused of wasting water. Releasing water early can also exacerbate downstream flooding and reduce warning and evacuation times. Conversely if they do not release water soon enough or for long enough then they are accused of neglecting to provide adequate flood mitigation to the downstream community if a major flood does occur. Gated spillways can provide dam owners with limited flexibility to control discharges during a flood event, but in the aftermath of the 2011 Brisbane floods many dam owners may now prefer not to have gated spillway structures on their major dams to avoid the potential public criticism and legal risk which can result.

For pre-releases to be considered, it is crucial that the rainfall predicted actually occurs so that supply security is not lost. The Bureau of Meteorology can forecast rainfall events quite a number of days prior to the event with a certain level of confidence, however, the confidence levels increase as the event gets closer. Should the rainfall (location, duration, intensity) not occur as forecast and pre-releases have been made, then water that has been captured at some cost will have been lost. Also, if the rainfall event occurs downstream of the dam and pre-releases have been made, then this will have exacerbated the downstream flooding, causing the flood levels to be higher and reducing evacuation times.

Pre-releases from the dam may have the following issues:

- They could cause damaging flows downstream earlier than waiting for the dam to fill;
- Reduced warning times for evacuations or moving stock, goods or equipment;
- Earlier closing of the downstream bridges.
- Aggravated flooding due to the possible coincidence of the pre-releases arriving at the same time as flood waters from downstream sub-catchments
- The adverse impacts on water supply security should the rains (and more importantly, the inflows) not eventuate.

In summary, whilst pre-releases can create some airspace to capture and mitigate small events there is a risk that pre-releases could exacerbate flooding and reduce evacuation times, since flood events may not occur as predicted and timing is critical.

***Alternate gate operating regime***

If the dam is fitted with gates which are operated in sequence to enable the dam to pass flood waters while maintaining it's safety. Alternate gate operation methods may have some benefit for small floods, by slightly increasing the duration of flooding downstream, but will have little impact for larger flood events in terms of water levels in critical locations downstream. Hence, alternative gate operational rules do not often provide significant flood mitigation benefits.

***Permanent lowering of FSL – creating permanent airspace for flood mitigation***

Permanent lowering of the storage can be quite effective in providing flood mitigation benefit, depending upon how much the FSL is lowered; however the option is often not viable for most dam owners who cannot afford to compromise water security and the annual allocation of water which is depended upon for revenue.

The provision of permanent airspace in a dam has significant benefits over temporary flood mitigation airspace (i.e. pre-releasing). There is a guaranteed flood mitigation capacity (assuming the airspace has been re-created after the previous inflow event); the amount of flood mitigation which is available is not dependent upon accurate rainfall and flood forecasting; it slows the rise of the flood downstream, giving more time for emergency planning and evacuation; downstream flood peaks will be reduced for the same amount of airspace because the captured flood waters can be slowly released after the flood whereas with pre-releases the waters need to be released quickly before the flood; the available water supply is more certain in that if water is pre-released and the rainfall and inflows are less than forecast (generally this is the case) then water is unnecessarily lost. The benefits reduce as floods become larger.

In theory, the creation of permanent airspace is a more effective option than pre-releasing. However, there are costs and, depending upon how much airspace is created, and how demand for water increases over time with population growth, climate change impacts and the impact of water conservation and demand management initiatives, the need for alturnate water sources would be brought forward. This is a significant matter for long term water supply planning.

***Physical modification of the dam***

Physical modification of a dam, usually by raising the dam wall in combination with high level spillways to create additional temporary flood storage, can be a viable option for some dams and is generally the most effective means of providing substantial flood mitigation benefits; however, the capital costs associated with such works are typically high. NSW Public Works has undertaken various studies on dams that investigate the feasibility of modifying the dam for flood mitigation. Construction works for these projects can be very high, particularly considering that the works must be completed on an operational dam without interrupting the water supply function, in particular adverse construction impacts on the lake's water quality.

When assessing the potential for adapting a water supply dam into a dual function water supply and flood mitigation storage the following process is generally adopted:

1. Assess the feasibility of adapting the dam by identifying the potential methods of modifying the dam for flood mitigation and costing of the options.
2. Model (hydrologic and hydraulic) the dam, its downstream inundation and flooding consequences for a number of selected potential arrangements over a range of flood scenarios to assess and quantify flood damages, both direct and indirect,
3. Select the most cost effective and beneficial solution within stakeholder budget expectations.
4. Design and optimise dam modification works that will provide the greatest value-benefit to the downstream community.
5. Employ construction methodologies and staging that ensure water supply is uninterrupted, water quality is protected and the flood security of the dam is maintained throughout the construction. This can be very challenging and inevitably results in increased project costs.

The effectiveness of flood mitigation schemes is usually evaluated based on the reduction in peak dam outflows compared to the peak flood inflows for a range of flood events (refer to Figure 1). This is followed by an assessment of the impacts downstream of the dam for the selected configurations. Ultimately, it is the reduction in the downstream water levels achieved rather than the peak outflow which is the key outcome for evaluation of the flood mitigation benefits. It should be noted that whilst the level of downstream flooding is reduced, the time that the downstream area is inundated is extended. This 'trade-off' must be carefully assessed.

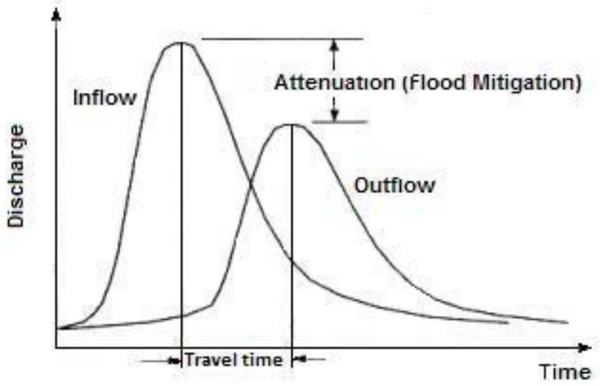


**Figure 1: Flood hydrographs**

A key decision for the dam owner is whether to design the flood mitigation works to cater most effectively for very large floods (up to the Probable Maximum Flood (PMF)); relatively small floods such as the 1-in-100-year Annual Exceedance Probability (AEP) event; or somewhere in between. The level of raising and the spillway arrangement must be optimised to achieve the targeted solution.

Due to water demand and potential water security risk the dam FSL cannot usually be lowered significantly during the construction period. Therefore, the design and construction staging must be able to accommodate the existing dam water supply function and operations throughout the entire construction period.

The following options are often assessed:

- Mass concrete raising/buttressing for arch or gravity dams
- Downstream rockfill and/or earthfill embankment or rockfill buttressing
- Upstream rockfill and/or earthfill embankment

Other raising options may also be considered. The provision of a hydro-electricity generation system could be viable for some dams and may be incorporated into the modifications works. The future revenue from hydro-electricity production could offset some of the costs incurred to modify the dam.

The above options will generally also involve modifications to the spillway arrangement. A high level spillway in combination with raising the dam wall is often required to provide large flood mitigation storage (air-space). The modifications to the spillway will have a significant impact on the appurtenant works at the dam including the outlet works and dam access. The raising options also present varying degrees of challenges to maintain water quality during construction. These considerations need to be accommodated in the final design and construction sequencing, resulting in increased capital cost.

The availability of construction materials on or near the site, along with the dam site geology are critical in determining which options are feasible and cost effective.

To achieve the optimum solution for flood mitigation a range of modified dam wall and spillway configurations must be modelled by routing a range of floods through the proposed configurations. Downstream damages assessments would be used to compare the benefits which could be achieved for each option and a cost-benefit study would be utilised to determine the preferred option.

*Funding complexities*

Physical modification of the dam is often the most feasible option available to the dam owner, if significant flood mitigation benefits downstream of the dam are to be achieved. However, given that the capital cost will be high and there are a number of different stakeholders that will benefit from the additional flood mitigation, the key question is: Who pays for the project?

If the project were to proceed then it is expected that significant flood mitigation benefits would need to be achieved for both small and large flood events. This is likely to provide significantly lower flood risk and lower insurance premiums for large downstream populations.

There would be many beneficiaries from the provision of flood mitigation but whose responsibility is it to fund the project and the related ongoing maintenance? Recovery of the capital costs through water charges or fixed levies results in all customers subsidising a benefit to a limited number of properties. The downstream communities benefit from lower risk of flood damage to their properties and lower insurance premiums. Federal, state and local government benefit from lower risk of damage to infrastructure and reduced liabilities. Insurance companies also benefit, with less risk and better market opportunities. Should all of these potential stakeholders be asked to contribute to the project funding and will legislative changes be required to facilitate the process?

*Maintaining reduced flood risk*

Another aspect which needs to be considered is how to ensure that flood risk reduction is maintained into the future if such a project was undertaken. Much of the risk downstream of the dams often develops due to the allowance of development and other activities in high flood risk areas. If the proposed works were implemented and the downstream risk is significantly reduced, large areas of land, which were previously below the flood planning level and therefore unusable, would become attractive to developers and other business interests. These groups would likely lobby to have land opened up for use and for the removal of existing land use restrictions. Although this would benefit many it may also lead to negation of some of the risk reduction that had been achieved. It would be the responsibility of state and local government agencies to ensure that the flood mitigation benefits which are achieved are maintained after construction and into the future, or the issue may return. Downstream flood evacuation routes still need to be upgraded as the works will not eliminate downstream flooding, only reduce the height and frequency, thus damages.

*The interaction between flood mitigation measures within a flood risk management system*

As outlined by Petry (2002), effective flood risk management requires a broad approach which should incorporate an integrated view of strategies, polices, plans, specific projects and other measures of social and institutional character. The selection and implementation of effective and optimised strategies is complex and there is a need for the integration of structural and non-structural measures to achieve successful flood risk reduction solutions.

If a dam is adapted for flood mitigation in a region subject to high flood risk, this measure is usually one of many strategies adoped for the community. The region’s flood risk management strategy will likely include various other structural and nonstrctural flood mitigation measures also outlined by Petry (2002) and shown in Table 1 below:

**Table 1: Overview of structural and non-structural flood mitigation measures**

| | | |
|---|---|---|
| **Structural measures** | Extensive<br>- reshaping of land surface<br>- protection from erosion<br>- delay of infiltration<br>- urban works | Intensive<br>- levees, dikes, floodwalls<br>- dams and reservoirs<br>- floodways and diversion works<br>- polders and fills<br>- drainage works |
| **Non-structural measures** | Regulation<br>- land zoning<br>- coding | Flood Defence<br>- forecasting<br>- warning<br>- flood proofing<br>- evacuation<br>- relocation |

All aspects of the flood risk management strategy which are affected by the dam, directly or indirectly, will need to be reassessed in light of the changes to water movement during flood events which will result from the dam's adapted function. The interaction between structural flood mitigation measures within a floodplain can be complex, requiring detailed hydrologic and hydraulic assessments to examine the impacts of changes in the system.

One example is levees located downstream of a dam which has been adapted for flood mitigation. Levees are commonly used to protect populations at risk from flood waters and are often located very close to the populations which they protect.

The flood mitigation benefits provided by dam modification works will result in reduced water levels at the location of downstream levees for a particular AEP event. Hence, a levee designed to provide a level of protection (e.g. the 1-in-100yr AEP flood) will then be able to cater for events which are rarer or more extreme than were originally intended. This is not a negative outcome for the community; however the significant investment in infrastructure which has transpired may not have occurred in the most appropriate manner.

Public lobbying for a particular flood mitigation solution can also influence decisions without an adequate assessment or understanding of the whole of floodplain implications. Decisions which result in significant changes to a region's flood risk management strategy need to be assessed in detail, considering the interaction between different structural measures within the system and the effect on response and planning approaches, to ensure that allocation of funding provides the greatest value-benefit to the community.

## Case Studies

This section will review two major dams located near a large urban town centre prone to flooding as a case study. Some international examples of cities facing similar flood related issues to those in Australia are also examined.

*Case Study: Wivenhoe Dam and Somerset Dam – 2011 Brisbane Floods*

Somerset Dam on the Stanley River and Wivenhoe Dam on the Brisbane River were constructed to provide both urban water supply and flood mitigation. Somerset Dam is located upstream of Wivenhoe Dam. The two dams have a combine storage volume of 1.4 GL used for water supply and over 2.6 GL of temporary flood storage available to provide flood mitigation and to ensure that the dams have adequate flood capacity. The dams are operated to meet a range of flood mitigation objectives including impacts on the rural community, urban flooding and dam safety. Both dams have gated spillways which allow the dam operators to have some control over the discharge from the dam during a flood. The degree of control the dam operators have is dependant upon the and the size and type of the flood event.

**Figure 2: Wivenhoe Dam during 2011 floods (Photo: Dean Saffron)**

Between 2003 and 2006 Wivenhoe Dam was upgraded to increase the flood handling capacity of the dam, in terms of overall stability, following a revision of the design rainfall events by the Bureau of Meteorology. NSW Public Works had significant involvement in the design of the upgrade works as part of the Wivenhoe Alliance. This upgrade involved the construction of a new auxiliary spillway through the right abutment of the dam, strengthening the existing spillway and raising the dam crest. A key component of the upgrade was to preserve the pre-existing flood mitigation capacity of the dam.

Since its construction in the 1980s, Wivenhoe Dam, in conjunction with Somerset Dam, has provided extensive flood mitigation benefits to the downstream community. During January 2011, Queensland experienced an extensive wet season with significant flood events occurring along many of the major river systems. The Brisbane River basin experienced large rainfall totals resulting in major flooding through the city of Brisbane. Both dams provided substantial flood mitigation benefits to the downstream community by both delaying the onset of flooding and reducing the peak outflow and duration of flooding downstream of the dam.

**Figure 3: Flooding within Brisbane suburbs in 2011 (*Photo: REUTERS/Tim Wimborne)***

However, following the flood event, as examined by Raymond (2011), the public perception, driven by media coverage, was that the dam had failed to prevent flooding, without any understanding of the complex interaction between downstream tributaries and the limitations of the existing infrastructure. Managing flooding downstream of Wivenhoe Dam is difficult because the water released from the dam combines with other rivers downstream of the dam. Floodwaters from Lockyer Creek and the Bremer River enter the Brisbane River downstream of Wivenhoe Dam and therefore cannot be controlled by the dam. These downstream rivers alone can cause significant flooding in Ipswich and Brisbane.

The ongoing Wivenhoe and Somerset Dam Optimisation Study (WSDOS) is reviewing the flood mitigation operating rules to determine if there is scope for improved outcomes, but there remains the key issue of what can actually be achieved by the existing infrastructure. The focus is on achieving the best balance of the three key objectives; water security, flood mitigation and dam safety. In order to optimising the operations of Wivenhoe and Somerset dams it must be recognised that each potential flood will be different and that the operational strategies adopted must provide balanced outcomes across a large range of flood possibilities.

***Some International Cases***

According to Munich Re (2013), global economic losses from flooding exceeded $19 billion in 2012. Australia is one of many counties facing significant flooding risk from an international problem which will only be become more critical in the future as population of flood prone land increases and as a result of the effects of climate change as outlined in Hallegatte et.al (2013).

A recent example which highlights the potential risk and the need for flood mitigation measures in flood vulnerable cities is the “Great Flood” of Alberta, Canada, which occurred in June 2013. The flooding resulted in the loss of four lives, displaced thousands from their homes, disrupted hundreds of businesses and caused significant damage to private and public property, land and infrastructure.

As outlined by Alberta WaterSMART (2013), in response to the devastation, a variety of flood mitigation options are being investigated including utilisation of both on-stream and off-stream storages for flood control amongst other structural and non-structural measures. The dam related options identified are proposed for a number of existing structures and include permanent lowering of storage levels and increase in flood mitigation volumes through dam modifications as well as alternate operating conditions.

Heidari, (2009) has developed a structural master plan of flood mitigation measures for the Dez and Karun river floodplain in Iran. The study assessed construction costs verses expected value of damage reduction for a range of structural mitigation options. The mitigation options including detention dams, levees and dykes and flood diversions, were investigated and impacts were assessed for whole rivers reaches. The expected value of annual damage and damage-reduction were determined for the options and economic indexes for each plan were evaluated.

The most effective flood mitigation measures were found to be as follows, listed in order of effectiveness:

1. a detention dam on Shoor river (tributary in downstream of the Karun basin)
2. a diversion channel from Big Karun from upstream of Ahwaz city to estuary
3. levees in downstream of Ahwaz city

As outline above, the study found that a detention dam followed by a flood diversion channel were the most effective flood mitigation solutions in this case. Enforcing flood control operational procedures for upstream multipurpose reservoirs was also found to be effective.

Floods also pose a serious threat to people and monuments in Petra which is located in the southwest region of Jordan. Al-Weshah & El-Khoury (2000) have assessed mitigation strategies including afforestation, terracing, and the construction of check and storage dams, as well as various combinations of these measures, to determine the effectiveness of such options. A flood simulation model depicts reductions of up to 45% for the 1-in-100-year flood in flood-peak flows for storage dams alone.

These are just a few examples of dams used for flood mitigation and the critical role they can play in providing substantial flood mitigation benefits to communities in various locations around the world. Generally the use of dams for flood mitigation is part of a range of structural and non-structural measures implemented to achieve an effective flood control solutions for vulnerable communities.

## Conclusion

The 2011 Brisbane floods sparked significant community interest in the functionality of dams, particularly around using water supply dams near major cities for flood mitigation in Australia. Wivenhoe and Somerset dams in Brisbane are good examples of dual purpose water supply and flood mitigation storages which have provided substantial flood mitigation benefits to their downstream communities. There may be the opportunity for some major water supply dams within Australia to be adapted for flood mitigation, with the potential for very significant benefits to downstream communities.

Modifying an existing water supply dam for flood mitigation can be complex and very expensive, and funding such projects is difficult and may require legislative changes. It is suggested that such projects could be undertaken via a public - private partnership with stakeholders that are likely to benefit from the works, including the Insurance Industry, being asked to contribute both financially and in kind support. Additionally, if flood mitigation works are undertaken then it is important that the risk reduction is maintained into the future through appropriate land use planning decisions by government agencies.

Lastly, decisions which result in significant changes to a region's flood risk management strategy need to be assessed in detail, considering the interaction between different structural measures within the system and the effect on response and planning approaches, to ensure that allocation of funding provides the greatest value-benefit to the community.

## Acknowledgment

The authors gratefully acknowledge the support of NSW Public Works, Seqwater and State Water Corporation in the publication of this paper.

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