Resilience policy for flood risk transferred from private to public dams: insurance and accounting issues

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Abstract

Despite issues with inadequate private water storage and risk management in catchments above large public dams, no comprehensive resilience policy framework has been developed to integrate the actions of both public and private actors. The research seeks to investigate what elements of resilience policy should be adopted for the management of private and public catchment dams to prevent potential cumulative flood risks to communities under conditions of more frequent and/or severe extreme weather events due to climate change. This investigation is undertaken through a review of prior research and a case study of the Wivenhoe Dam catchment in Queensland, Australia. Results find that while recent flooding focused attention on the role of the large public Wivenhoe Dam in preventing the flood impact on Brisbane, less attention of was paid to smaller private dams upstream in the catchment and the cumulative failure risk to Wivenhoe and other large public dams. The paper presents a preliminary development of generalisable guidelines for robust and rapid resilience policy. Such policy would facilitate a range of approaches/options to cost sharing amongst stakeholders including insurance and technological tools to mitigate the risks posed by cumulative private dam failures in catchments of large public dams.

Keywords

Resilience policy; private dam failure; insurance; flood risk transfer; Wivenhoe dam
1. Introduction

One of the expected consequences of human-induced climate change and global warming is an increase in the frequency and/or intensity of extreme weather events, including instances of heavy rainfall, cyclones, and flooding (Emanuel 1987; 2005). Extreme weather events often occur unexpectedly or with little prior warning and – depending on their magnitude, duration and occurrence relative to the location of population centres – can become major disasters and pose a significant challenge to an effective response. Recent weather extremes such as the extensive flooding in Queensland, Australia in 2011 have focused attention on the human and economic costs of such weather-related disasters and on the challenge for affected communities to be resilient to the risks. More than 78% of Queensland was declared a disaster zone, and over 2.5 million people were affected (Queensland Floods Commission of Inquiry 2011). The flooding also called into question the flood mitigation effects of existing infrastructures, in particular the large Wivenhoe Dam which was built for water supply and flood mitigation purposes for Queensland’s major population centre, Brisbane, and surrounding areas.

Resilience to risk, such as that posed by extensive flooding, has been defined as the ability of a system to resist, avoid and recover from shock (Folke et al. 2002; Haimes 2009). In this sense, resilience is the counterpoint of vulnerability, which refers to the inherent state of a given system (e.g. infrastructure, social, ecological, organisational) that is exposed to the possibility of adverse effects. However, the nature of the aforementioned systems and their inherent vulnerability give rise to many different types of resilience: for engineers, resilience measures the infrastructure’s ability to withstand impact and absorb and release energy (McAslan 2009); for sociologists, resilience refers to the capacity of communities to cope with stress and change (Norris et al. 2009); for ecologists, the term measures the ability of ecosystems to absorb change and continue to function (Klein et al. 2004); and for organisational theorists, resilience of a business describes the capacity to use disruptive events to continue and grow a business (Parsons 2010).

In relation to building resilience against flood risk, however, there currently exists a lack of insight into how the resilience of larger public dams can be strengthened and thus resulting impacts can be avoided. We therefore suggest that development of guidelines for resilience policy is required. For the policy context, a single definition of resilience is neither required nor essential, as the concept must be considered from many different viewpoints to develop adequate policy (McAslan 2009; Prosser & Peters 2010). After the occurrence of the Brisbane flood, there was much discussion about the role of the Wivenhoe Dam infrastructure in preventing the flood risk to Brisbane, with calculations by engineers suggesting that most of the flooding that damaged tens of thousands of homes would not have occurred if extra capacity for flood storage had
been available (QLD Floods Commission 2012). However, these discussions do not take issues upstream of public dams into consideration, in particular the potentially serious problems associated with water storage in smaller, non-referable, private dams (often farm dams) in the catchment area of the public dam, and the increasing risk from multiple non-referable private dams failing in extreme weather events (Pisaniello et al. 2012). The key issue here is that the private and public dams are interconnected by infrastructure to prevent flood disasters, but are operated, managed and overseen by actors that are institutionally fragmented and pursue individual management goals because of sub-optimal local decision making rather than global optimal decisions for flood risks to communities in any catchment (De Bruijne & Van Eeten 2007). Changing climate conditions and forecasts of increases in extreme weather events mean that these risks will only increase (Winn et al. 2011).

If a series of private dams throughout a catchment are managed inadequately then they can fail in a cascade manner where volumes of water from one dam unexpectedly are released into another, leading to multiple failures. Examples of the actual seriousness of cumulative dam failures because of a lack of effective resilience policy include: in China the Shimantan and Banquia dams failed in 1975 because of the cumulative failure of 60 smaller upstream dams, resulting in the deaths of 230,000 people (Yi Si & Dai Qing 1998); in the United States, the 5m Evans and Lockwood dams, which held only 89ML and 39ML of water respectively, both collapsed in a cascade manner in 1989, devastating communities and killing 2 people (Graham 1999); and, in Quang Binh Province, Vietnam in 2010, 85,000 homes and businesses were flooded and at least 16 people died after water rose more than one metre over a large public dam following heavy flooding in the catchment which contained many small dams (Thanh Nien News 2010).

In Australia, there are in excess of 735,000 private farm dams, many of which are in catchment areas of large public dams (Baillie 2008). The Wivenhoe dam in Queensland is an example of a public dam with many private dams upstream of it (McJannet et al. 2008, p.10). Investigations into the cause of the 2011 floods in Queensland concentrated on the flood mitigation capability and management of Wivenhoe public dam (Queensland Floods Commission of Inquiry 2011). Yet, there has been little research on the role of private dams upstream of public dams and the potential impact on public dams in mitigating the floods adequately and, in turn, the devastation downstream (van den Honert & McAneney 2011). Past research in other Australian catchments has found that individual spillway outlets can become inadequate because of poor design, lack of maintenance and/or spillway blocking practices (Pisaniello et al. 2011a; 1 Referable dams are identified as (a) over 10m in height with a storage capacity of more than 1500ML; or (b) more than 10m in height with a storage capacity of more than 750ML and a catchment area that is more than 3 times its maximum surface area at full supply level. (Water Supply (Safety and Reliability) Act (2008), Section 341(1)).
they also increase the likelihood of collective dam failure by overtopping even during small floods, thereby putting large, end-of-line public storages at risk of excess flooding and failure and downstream communities at serious risk (Pisaniello 2009).

Despite the urgency of the problem of inadequate private/on-farm water storage risk management in catchments above large public dams, significant deficiencies in resilience policy remain (Pisaniello 2009; Pisaniello et al. 2011a; 2012). This paper raises the need to recognise the actual and potential risk’s associated with cumulative private dam failure as a significant contributor to Wivenhoe dam’s inability to mitigate floods adequately in 2011 simply because of the large number of private dams contained within its catchment. The paper demonstrates that even if such a cumulative failure phenomenon was not at play in 2011, the potential for it to come into play under future, more extreme rainfall events is considerable, in which case a more disastrous public dam collapse can result. Hence the urgent need for furtherer investigation of the roles of public dams in mitigating flood risk and to develop preliminary guidelines for resilience policy.

Resilience policy, in the context of this paper, is policy that recognises current and future risk of catastrophic damage to communities, and works to manage and reduce those risks (Prosser & Peters 2010). Further understanding is required of the (1) scope of current resilience policy covering dam failure flood risks in catchments with institutionally fragmented actors, (2) stakeholder water storage risk perceptions of a test catchment in Australia which has recently experienced dam-failure related disaster, and (3) the most appropriate elements of resilience policy designed to mitigate risk and to prevent cumulative cascading flood impacts, particularly given the increased risk of weather extremes due to climate change. The paper proceeds as follows: Section 2 establishes the cumulative risk problem and describes it in the context of the Wivenhoe Dam catchment. Section 3 provides a review of the applicable water risk management frameworks in Australia, followed by presentation of elements of optimal resilience policy (Section 4). Discussion of the test catchment case study in Section 5 displays results of the study, including relevant analysis of the catchment in addition to the results of the Queensland Flood Inquiry. Section 6 presents preliminary resilience policy guidelines for preventing cumulative cascading flood impacts. Finally, Section 7 provides discussion and conclusion with presentation of implications of the study and areas for future research.
2. The ‘cumulative’ risk transferred from private to public catchment dams

In catchments of large public dams, such as the Wivenhoe Dam in Queensland, the existence of large populations of small private dams creates two types of risk which are inter-related: (1) stand-alone, and (2) cumulative risk to communities. Many private dams contain stand-alone risk (Type 1) because of improper design, in particular, flood capability design, general lack of review and maintenance, and other inadequate on-farm practices. For instance, landholders hire contractors to construct dams but these contractors are not typically trained or skilled in the design of dams (Pisaniello 1997; Pisaniello & McKay 2005; 2007). Private owners tend to neglect maintaining dams because of a sense of complacency (Webster & Wark 1987; Pisaniello & McKay 2005; 2007) whilst the typical probabilities required for design floods are beyond the average farmer’s comprehension (Pisaniello & McKay 2005). The result is that downstream communities are placed at risk. During periods of drought, water allocation policies/restrictions tempt farmers to block spillways in order to increase potentially non-entitled water captured in dams (McMurray 2004; Pisaniello & McKay 2005; 2007). The outcome is that already under-designed and un-maintained spillways become more inadequate and unsafe and downstream communities are subjected to even greater risk.

Essentially the stand-alone risk described above is transferred to the ‘cumulative’ risk category (Type 2) leading to risks to resilience of communities downstream of cumulative flood failure of small dams in catchments. As individual spillway outlets become inadequate because of under-designing, lack of maintenance and spillway blocking practices they also increase the likelihood of dams failing collectively by overtopping during even small floods, thereby putting large, end-of-line public storages at risk of failure (Pisaniello 2009). Global warming adds to the problem by causing extreme flood events to become more likely (UN IPCC 2007) with potentially catastrophic downstream consequences. If small dams are located upstream with potential to cause cumulative failure of larger dams then ‘the combined effect of multiple dam failures should be the basis of the hazard category of the upper dams’ (ANCOLD 2000a, p.10).

Cumulative flood risks were of concern in a flood study of the Kangaroo Creek Dam, one of South Australia’s largest and highly hazardous public dams (LDC & SMEC 1995), where it was found the peak inflow to Kangaroo Creek Dam would increase fourfold if all small dams in the catchment failed in a 1-in-200 years extreme flood event (Kazarovski 1996). The small dams’ cumulative failure was a reasonable assumption given that Pisaniello and McKay (2005; 2007) found most small dams cannot pass a 1-in-200 years design flood. This exacerbated flow to Kangaroo Creek dam would exceed its spillway capability, which should otherwise be able to pass a 1-in-10,000 years to Probable Maximum Flood
(PMF) event, putting the resilience of downstream communities at unacceptably high risk (Kazarovski 1996) and demonstrating the need for resilience policy for catchment dams in cascade/cumulative scenarios (LDC & SMEC 1995).

It is therefore important to realise that while extreme events (larger than in the 2011 Queensland floods) which can lead to the collapse of large public dams (e.g. 1-in-10,000 years to PMF events) are rare events they are plausible. For example, a 6 hour storm at Dapto in NSW in 1984 was recorded as being a near Probable Maximum Precipitation (PMP) event when compared against estimated values using Bureau of Meteorology (1994). Also, Nathan et al. (1994) compared PMF estimates derived using current best practice PMPs for 56 varying-sized catchments in South Eastern Australia with observed maximum floods from the same region and around the world. The comparison is illustrated in Figure 1 and shows that extremely rare floods approaching PMF magnitude (as estimated using current best practice) have occurred and are therefore realistic. The cumulative failure of private dams in catchments of large public dams can serve only to bring about PMPs/PMFs more frequently and/or intensify the magnitude of a PMP event so that the PMF flow is greater than that estimated for the design of the public dam’s spillway. This is clearly demonstrated by the Kangaroo Creek study and can ultimately lead to collapse of a public dam due to overtopping with disastrous consequences as illustrated by the examples provided above.

![Figure 1: Comparison of observed flood peaks with PMF peak values (log linear transformed variable values) estimated for a range of Australian catchments (Source: Nathan et al. 1994)](image-url)
This paper therefore examines how to design a comprehensive resilience policy that can help mitigate the risks to communities transferred from private to public dams in catchments. The research seeks to do this by answering the following research question:

What range of elements of resilience policy can be adopted for the management of private and public catchment dams to prevent future cumulative flood threats to communities under conditions of increasing risk and more frequent and/or severe extreme weather events?

It is argued that the expected increase in frequency and/or intensity of weather extremes and related disasters will make it indispensable to formulate and implement resilience policy for dam operators, and requires urgent attention in national- and state-level institutional arrangements and also insurers’ strategies. This suggests that there is a real need for comprehensive and coordinated resilience policy across private and public actors to increase the resilience of communities to dam failure flood risk in a changing climate.

The methods used to address the research question include a literature review and case study. Firstly, the Australian, and Queensland context of private dam management resilience policy setting for private to public transference of flood risk will be reviewed. Approaches to and associated elements of private dam management resilience policy in this context will then be considered based on international reviews by Pisaniello & McKay (2007) and Pisaniello et al. (2012). The reviews will be followed by a desk-top based case-study of the Wivenhoe catchment in Queensland where many private dams suffered flood impacts and uncertainty associated with inadequacy of a major public dam. The case study method, which will include a content analysis of the full Queensland Floods Inquiry reporting enables exploration of contemporary phenomena and is useful for issues such as climate and risk problems that require many different viewpoints brought together (Yin 2008; Ettlinger 2009). The following section will provide background of private dam management resilience policy in Australia.

3. Management of water risk in Australia

Management of water risk in Australia is a significant issue, not only because of the high variability in rainfall (Lake & Bond 2006) which is set to increase (UNIPCC 2007), but because of the need of stakeholders at all levels to action a response to the critical agenda of climate change and water risk (Linnenluecke et al. 2011, 2012). In Australia, the number of flood disasters is on the rise with floods estimated to be the most costly of all natural disasters causing large financial damage to infrastructure, property, individuals, communities, ecosystems, land and crops, and farming operations. In Queensland in 1998 and 1999 the summer floods
adversely affected 83,500 people and cost AU$990 million, only AU$184 million of which was covered by insurance (Geoscience Australia 2010). The recent 2011 summer floods in Queensland realised 56,200 claims to insurers, with an insured cost of $2.55 billion (van den Honert & McAneney 2011; Herald Sun 2011).

Unsafe water storage caused by inadequate on-farm water storage risk management is part of the broader water management problem because many private dams have inadequate flood capabilities and are either inadequately designed (for example, spillways too small) or inadequately risk managed (for example, spillways artificially or naturally blocked) (Pisaniello & McKay 2003; Pisaniello et al. 2011a, 2012). The cumulative failure of these dams during medium to large storm events can lead to higher than expected flows into large public dams with two key potential consequences. First, the actual design flood capability of a public dam and, hence, resilience possible when faced with unexpected catastrophic public dam failure for downstream communities, is much less than expected. Second, the flood mitigation capability of a public dam is compromised, leading to excessive flood damage to downstream communities.

Climate change is posing further risk to water systems already under considerable stress (Linnenluecke & Griffiths 2012). Climate change increases the likelihood of extreme rain patterns in Australia, leading to the risk of flash floods, which are likely to increase in frequency in middle and high latitudes (UNIPCC 2007): hence water risk not managed adequately within effective and well-implemented policy will result in dams unable to handle extreme flood events and more frequent failures. Water management in times of flood, further exacerbated by climate change, involves considerable uncertainty and risk to which many communities are not resilient. Furthermore, farmers storing more than their entitlement via spillway blocking tactics create an unsafe dam structure, which can generate devastating consequences at individual and cumulative levels (Pisaniello 2010; Pisaniello et al. 2011b, 2012). The following sections review the private dam management policy setting in Australia and then more specifically, in Queensland.

3.1 Private dam management policy setting - Australia

Despite the risk and uncertainty posed by cumulative dam failures, there are deficiencies in the way these are regulated throughout the whole of Australia. Federally, at the level of the Australian Government, there is little involvement in mitigating or increasing resilience to the risk and uncertainty of water storage since the overturning of the riparian doctrine in the late 1800’s which served as an institutional ‘first rights’ mechanism to overcome disputes over water storage issues (Musgrave 2008). For fairness of water sharing, each state now retains ‘superordinate legal status over water resources’ and their storage despite suggestion that a federal
approach would leave less room for interpretation by, and differences between, states that currently exist (Crase 2008, p.4). The Council of Australian Governments (COAG) competition policy reforms between 1994 and 2004 are allowing for a shift to a more national institutional focus and restructuring reforms for each state through a National Water Initiative (NWI) based around principles of sustainable development (McKay 2008). From the perspective of resilience to water storage risk, there are no institutional mechanisms to govern the safety of on-farm water storage at a federal level.

From 1994 each Australian state had the opportunity to look holistically at water management and revised their water laws to incorporate some form of resilience mechanisms for fair water storage. Since this time there have been moves for increased fairness in water storage in catchments in each state and territory (McKay 2008). Regulations on water entitlements to create titles more in line with the National Water Initiative (NWI) are in place in Victoria, New South Wales, Tasmania, South Australia, Queensland and the Australian Capital Territory, unlike in Western Australia or the Northern Territory (NWC 2005). However, interception activities, such as the capture of surface water in private dams are not being monitored uniformly across the country (NWC 2005). Despite the fact that on 3rd July 2008, the Australian Government and the governments of New South Wales, Queensland, South Australia, Victoria and the Australian Capital Territory (the basin states) signed the Intergovernmental Agreement on Murray Darling Basin Reform, to enter into water management partnership agreements (WMPAs) to give effect to water reforms in the basin, the response at a local level has been lagging (NWC 2011). These WMPAs are designed to improve rural storage and use in catchments in the basin but without significant improvements in knowledge of the amount of private dams and the water they capture in some states such as Queensland (DERM 2010) and Victoria (Brown 2011), there is a major part of these agreements missing (Lowe et al. 2005).

Despite research and overseas experience demonstrating that the cumulative impact of inadequate private dams in a catchment can pose catastrophic risk to downstream communities (see Pisaniello et al. 2012), privately owned dams are storing more than their entitlement in many Australian states (Pisaniello et al. 2012) and may pose significant cumulative failure risk, particularly in Queensland (DERM 2010). Yet, uniform resilience policy nationally has not been forthcoming (Pisaniello 2010). Land use policy for risk has also not prevailed- there remain deficiencies around Australia in regulating the significant amount of dam development in catchments and inadequate floodplain management (Smith & Handmer 1984; Yeo 2002, also see Groenhart et al. 2012 for an analogous study of bushfire risk). What endures is the dam owner responsibility that exists under common law to manage dams according to current standards (Pisaniello & McKay 2007). In Australia, these
standards are set by the Australian National Committee on Large Dams (see ANCOLD 2000a, 2000b, 2003). However, to rely solely on common law responsibility does not protect downstream communities from the risk of cumulative private dam flood failure (Pisaniello 2009; Tingey-Holyoak et al. 2011); therefore some states have responded individually. The development and surveillance of dams is controlled to varying degrees by legislation and regulations in Queensland, NSW, Victoria and Tasmania (ANCOLD 2000a). The case of Queensland will be considered in Section 3.2 below.

3.2 Private dam management policy setting - Queensland

Queensland is a state characterised by varied climate, landscapes and topography. The climate of Queensland differs throughout the state but generally there are hot, dry summers also characterized by heavy rains (Queensland Government 2012) resulting in strong water allocation policies for the many private dams in the heavily populated state (Table 1).

Table 1: Key characteristics of Queensland with relation to private dams

<table>
<thead>
<tr>
<th></th>
<th>Queensland</th>
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<tbody>
<tr>
<td>Human Population</td>
<td>4.60 million</td>
</tr>
<tr>
<td>Surface Area</td>
<td>1,730,648 km²</td>
</tr>
<tr>
<td>Number of main river catchments</td>
<td>14</td>
</tr>
<tr>
<td>Approximate Private dam Population</td>
<td>6,400</td>
</tr>
<tr>
<td>‘Referable’ dam population</td>
<td>46</td>
</tr>
<tr>
<td>Private ‘referable’ dam population</td>
<td>3</td>
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Queensland has key water allocation provisions incorporated into the Water Act (2000) and these include licensing requirements for any interference with water by capturing in private dams, depending on whether the catchment has regulated or non-regulated capture of runoff (Baillie 2008). A water entitlement system has established the power to regulate private dams, and in catchments water resource plans used these powers to prevent the construction of new private dams for other than stock and domestic purposes (Water Act 2000). Wivenhoe catchment, with the Somerset catchment, forms the largest and most important water supply catchment with dominant land uses being grazing (60%), native forests and scrub (32%), intensive cropping (3.5%) and rural residential (0.2%) (EPA SA 2007). South-East Queensland Water, which supplies water to customers in the region, only owns a small area of land and local councils retain responsibility for the assessment and approval of private dam development proposals in Wivenhoe (EPA SA 2007). On top of the
development approvals, existing private dams have flood failure risk protection provisions that focus on 'referable' dams only (DERM 2011). Oversight of all referable dams is undertaken by the Department of Energy and Resources Management (DERM) based on their own setting of failure impact ratings, for which DERM is given the power to assign under the Water Act (2000).

Prior to the introduction of the Water Act (2000) there were 1500 ‘referable’ dams under regulatory supervision as the then dam safety regulations captured all dams (i) greater than 5m in height with at least 50ML of capacity or (ii) greater than 10 m in height with at least 20 ML of capacity in accordance with ANCOLD guidelines (Allen 2001). The Water Act (2000) weakened this ‘referable’ dams criteria to capture only dams over 8m in height with a storage capacity of more than 500ML; or (b) more than 8m in height with a storage capacity of more than 250ML and a catchment area that is more than 3 times its maximum surface area at full supply level, and then they were only referable if they posed either a Category 1 or 2 Failure Impact rating2; hence only around 300 dams remained under regulatory supervision (Allen 2001). Currently under the Water Act (2000) and associated Water Supply (Safety and Reliability) Act (2008), there are failure impact ratings, oversight and accountability acknowledged for only 46 ‘referable’ dams that are over 10m in height with a storage capacity of more than 1500ML; or (b) more than 10m in height with a storage capacity of more than 750ML and a catchment area that is more than 3 times its maximum surface area at full supply level (Section 343(1) of Water Supply (Safety and Reliability) Act (2008)). There is also some confusion on the Department’s website with other guidelines and webpages identifying referable dams under the former criteria of 8m or 250ML (DERM 2010, 2011). Whichever definition is adopted, these dams are at present, the only ones that require failure impact assessments carried out in accordance with the department's guidelines (DERM 2010). Surveillance Reports and evaluation of these few dams are conducted as part of a periodic dam safety inspection (at five yearly intervals), although evaluation may be undertaken at more frequent intervals or at times of concern. Following evaluation, a Surveillance Report is required to be prepared by experienced dam engineers familiar with the entire history of the dam (DERM 2010). However, with so few dams now regulated the protection from flood failure is largely unmonitored, especially the risk posed by existing small dams that can still create great danger, especially at the cumulative level above a large public dam (Pisaniello & McKay 2005; Pisaniello et al. 2011a).

2 In Queensland, hazard rating is referred to as Failure Impact rating and ‘referable’ dams includes only those with either a Category 1 or Category 2 Failure Impact rating. Category 1 dams are those which have a Population at Risk (PAR) of between 2 and 100 people and Category 2 dams are those which have a PAR of more than 100 people (Water Act 2000 with relevant parts now substituted into the Water Supply (Safety and Reliability) Act 2008, Chapter 4).
Given the patchwork of public and private ownership structures of dams across Australia, the implications for managing water risk are still unclear. It is also unclear which factors are contributing or hindering the overall resilience of communities to risk, and which elements of resilience policy should be adopted to prevent future risks of cumulative dam failures with cascading flood impacts. Coherent resilience policy has not yet been developed. The insurance and risk management industries have had little interest in dam risk issues beyond those associated with individual large dams (Baecher et al. 1980). Given that there are deficiencies in on-farm water storage resilience policy development and administration (Pisaniello et al. 2011a; Tingey-Holyoak et al. 2011), combined with the fact that the insurance sector is one of the largest industries in the world, reaching virtually every home, farm and business in developed countries (Mills 2003), there is an opportunity for complimentary or alternative resilience policy development, particularly as it relates to issues impacted by climate change (Weekes & Hannaford 2007; Booth & Williams 2012). Therefore, the following section identifies elements of resilience policy from the literature in the context of the transfer of private to public dam flood risk, including insurance mechanisms.

4. Elements of resilience policy for preventing cumulative dam flood risks in catchments

For all systems resilience policy needs to encompass avoidance and resistance to shock (Folke et al. 2002). Emerging insights suggest that building resilience policy for human/environment systems, such as catchments containing private and public dams, is an effective way to cope with dramatic events and risk, such as that posed by floods (Prosser & Peters 2010). Policy can impede or create resilience depending on how it is developed and implemented, in addition to how the social-ecological system organises itself in light of policy. Resilience policy has the potential to contain the components needed for adaptation and reorganisations of systems so that they are more resilient (Folke et al. 2002). That is, when resilience policy is developed and implemented it has the potential to allow systems to cope, adapt or reorganise without social, ecological or organisational sacrifice (Gunderson & Holling 2002; Berkes et al. 2003).

Resilience policy is designed to encourage practice and behaviour that is novel and innovative (Folke et al. 2002) thereby enhancing the likelihood of sustainable management in environments where surprise is likely (Levin et al. 1998; Holling 1986, 1995). We argue that, resilience policy for private dam safety above public dams that facilitates safe private dam management is essential for resilience of downstream communities. And thus, resilience policy relies on a series of elements broadly considered in the context of the given management problem (Prosser & Peters 2010).
Based on previous extensive international reviews by Pisaniello (1997), Pisaniello & McKay, (2007) and Pisaniello et al. (2012), three main potential public and private approaches for private dam management resilience policy to account for private dam safety throughout a catchment and their sub-elements can be identified:

at public cost (a) upgrading the existing public dam, and/or (b) building new public flood mitigation infrastructure within catchments to absorb cumulative farm dam flood failures, such as wetlands, and/or (c) developing and implementing a government funded insurance scheme for private compensation in times of disaster;

at private (farmer) cost ensuring all individual farmers upgrade and properly maintain farm dams via either (a) command and control regulation, (b) quasi-regulation (e.g. insurance industry pressure), (c) self-regulation (e.g. industry body involvement) or (d) a combination of (a) + (b) + (c);

at private (downstream community) cost leaving current infrastructure, both public and private, alone and ensuring all property owners within flood plains have flood insurance against any type of flood damage, including that caused by cumulative farm dam failures.

To highlight the need for resilience policy, the above approaches identified are applied to a case-study of the potential for private to public dam flood risk transference in the 2011 floods in the Wivenhoe catchment in Queensland.

5. Wivenhoe case study

In the Wivenhoe Dam catchment in the summer of 2011, intense rains and a soaked upstream catchment containing thousands of private dams (McJannet et al. 2008 p.10) resulted in the Wivenhoe public dam reaching 190 per cent capacity (when 220 per cent capacity would have breached the dam wall, ABC (2011). Community, ecosystem and business resilience to risk was lost with many catastrophic consequences, including 23 people drowning (Australian Geographic 2011; van den Honert & McAneney 2011). The following sections detail the Wivenhoe catchment setting to provide context followed by application of the elements of private dam management resilience policy identified to the recent inquiry about the 2011 floods.

5.1 Catchment setting – Wivenhoe Dam

Runoff is controlled essentially by topography (drainage system structure, catchment area, etc.), land classification (land use, soil type, vegetation, etc.) and waterway capacity (conveyance and storage). These
characteristics dictate the catchment’s response to rainfall. In the Wivenhoe catchment (Figure 2), these characteristics have changed significantly over time because of progressive settlement and development (Harris et al. 2012). Rapid population increase in South East Queensland has meant that the networks of waterways and catchments in the region have been affected by issues such as dam development (Harris et al. 2012).

**Figure 2: Wivenhoe Catchment Map**

*South East Queensland catchment portion of map courtesy SEQ Catchments (2012).

The catchment’s major reservoir, the Wivenhoe Dam was built in 1985 (Table 2). The public dam had a major role during the 2011 floods which devastated Queensland (Sweet 2011), discussed in section 5.2.

**Table 2: Wivenhoe Catchment and Dam Characteristics**

<table>
<thead>
<tr>
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<th>Wivenhoe</th>
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<tbody>
<tr>
<td>Catchment</td>
<td>107.5km2</td>
</tr>
<tr>
<td>Dam completed</td>
<td>1985</td>
</tr>
<tr>
<td>Water supply storage of dam</td>
<td>1,150GL</td>
</tr>
<tr>
<td>Temporary flood storage of dam</td>
<td>1,450GL</td>
</tr>
<tr>
<td>Location of dam</td>
<td>Brisbane River Upstream of Lockyer &amp; Bremer</td>
</tr>
<tr>
<td>Number of private dams in catchment</td>
<td>971</td>
</tr>
</tbody>
</table>

(SEQ Catchments 2012; McJannet et al. 2012)
5.2 Possibility of cumulative failure risk transferred to the Wivenhoe Dam

The concept of private dams as ‘interceptors’ and reducers of streamflow in a catchment is well known (McJannet et al. 2008). For example, Schreider et al. (2002) undertook investigation in the Murray Darling catchments analysing the impacts of private dams on streamflow and showed that there were in fact significant trends of stream flow reductions in a number of catchments. There is also evidence of cumulative and cascade effects of these dams in times of flood, when their impact is directly related to flows into reservoirs (McJannet et al. 2008) such as the study of the Kangaroo Creek Dam discussed in Section 2 above. In both the case of reductions in streamflow and in the event of dam failure, the particular private dam management practice that creates a cumulative or cascade failure risk is inadequate spillway provision via either undersized and/or blocked spillways (see Section 2). For example, by intentionally under-sizing and/or blocking spillways farmers are able to store significant amounts of potentially non-entitled extra water; significant because small increases in storage height at the top end of the reservoir (which has a triangular prism-like geometry) results in large increases in storage volume (Pisaniello et al. 2012; McMurray 2004). But blocked spillways can also be the result of unintentional naturally blocked spillways due to lack of dam maintenance (Pisaniello et al. 2012). During times of extreme rainfall flood damages can be exacerbated from dam failures resulting from blocked spillways.

The conditions in Wivenhoe catchment suggest that significant risks to resilience (Section 2) exist, and, in the absence of strong private dam management resilience policy (Section 3.2), a lack of an overarching resilience policy may have been a factor in the 2011 floods. The ultimate flooding of Brisbane was termed a ‘dam release flood’ by the Insurance Council of Australia and whilst the dam operators were perceived to be acting in accordance with the operations manual for the dam, their modeling did not take account of forecast rainfall nor the variable catchment details (van den Honert & McAneney 2011), such as existence of small dam failures causing a sudden influx into the dam, when determining the predicted dam water level. This ultimately is what resulted in a sub-optimal water release strategy. Whilst future research is required to verify whether and to what extent cumulative private dam failure contributed to the inability of Wivenhoe Dam to effectively mitigate the floods in 2011 (as discussed in Section 7 under recommendations for future research) the past research discussed in Section 2 demonstrates the real potential for this occurrence under larger future rainfall events which can result in more disastrous public dam collapses. Hence, effective resilience policy addressing the risk posed by private dams in catchments of large public dams is needed and will be discussed in Section 5 as part of preliminary resilience policy guideline development. But firstly, the following section presents an analysis of the approaches to, and associated
elements of resilience policy identified to investigate the Queensland Flood inquiry responses for any relevant considerations or guidance.

5.3 Queensland flood inquiry

The findings of the 2011 Queensland Floods Commission of Inquiry were drawn upon. The Inquiry was established to examine the causes and circumstances of the Queensland Flooding and to provide recommendations in regards to flood preparation by governments at all levels, emergency services and the community, including the suitability of dam operational procedures for safety and flood mitigation and land use planning to minimise flood damages. The main data sources were the materials gathered and published by the Commission which were content analysed in accordance with the three approaches for private dam management resilience policy to account for private dam safety identified in Section 4. The Commission’s investigation was based on a large body of oral and written information, including evidence in the form of transcripts from formal interviews conducted as part of the Commission hearings as well as supplementary materials in the form of witness statements, exhibits (e.g., maps), reports, and various other materials collected. The Commission also drew on community consultations and public submissions in preparing the Interim Report and Final Report of the 2011 Queensland Floods.

The report was content analysed along the three main approaches to private dam management resilience policy (identified in Section 4) and the public or private nature of the approach (Table 3a and 3b). Table 3a highlights the public approaches to resilience policy through Approach 1(a), 1(b) and 1(c), which relate to public cost infrastructure upgrade, wetland development and/or an insurance mechanism. Table 3b highlights the private approaches, 2(a) to 2(d), and (3) that relate directly to private farming business’ and communities’ capacity to continue and manage the risk of a disruptive event under various direct, quasi-, and self-regulatory mechanisms. In addition, five themes emerged from the analysis (dams monitored in Queensland, scope of investigation, flood mitigation through catchment/floodplain management, development considerations, and local council/government involvement) which are detailed in the table. The clear message emerged from the report that private dams are not being considered. Tables 3a and 3b detail the results of this comparative analysis which are considered further in Section 6.
### Table 3a: Results summary table – public approaches to resilience policy (Queensland Floods Commission of Inquiry 2011)

<table>
<thead>
<tr>
<th>Theme identified in Flood Inquiry Report</th>
<th>1 (a) At public cost upgrade Wivenhoe</th>
<th>1 (b) At public cost create wetlands/levees</th>
<th>1 (c) At public cost create Government funded insurance mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dams monitored in Queensland</td>
<td>Not addressed</td>
<td>Not addressed</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Scope of investigation</td>
<td>'Seqwater has begun the task of conducting the scientific investigations necessary for the reviews [of the flood mitigation manuals applicable to Wivenhoe and Somerset ... Both studies will draw upon three separate investigations: into dam operations, water supply and floodplain risk management.'</td>
<td>Not addressed</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Flood mitigation through catchment/ floodplain management</td>
<td>'It appears that no Qld Government agency has wide ranging responsibility for flood mitigation. Such responsibility would include oversight of structural measures such as dams, levees and vegetation as a complement to non-structural measures such as land planning systems and emergency management. The Qld Flood Risk Management Activities Audit completed in November 2010 indicated that flood risk management activities are spread across a multitude of agencies and departments. The fact that no single agency has overarching responsibility is likely to lead to inconsistency and gaps in policy.'</td>
<td>Not addressed</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Development considerations</td>
<td>Not addressed</td>
<td>'The task of keeping models up to date is difficult in catchments where a significant amount of development occurs. The process of updating the model must take account of matters such as the placement of fill, the construction of flood mitigation devices such as dams or levees, and the effect of development in the upper part of the catchment on downstream flood levels. This process is made more difficult for a council by uncertainty as to when works approved will in fact be constructed.'</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Local council/ government involvement</td>
<td>'There is certainly a good deal of room for improvement in planning for emergency response ...Local councils which do not own referable dams have no part in their regulation or operation, whether for water supply or flood mitigation purposes. By way of example, the Brisbane City Council, Ipswich City Council and Somerset Regional Council play no role in relation to the operation of Somerset and Wivenhoe dams.'</td>
<td>'Government agencies need to engage in a process of floodplain management involving a combination of land planning and building controls, emergency management procedures, and structural mitigation measures such as levees and dams'</td>
<td>Not addressed</td>
</tr>
</tbody>
</table>
Table 3b: Results summary table – private approaches to resilience policy (Queensland Floods Commission of Inquiry 2011)

<table>
<thead>
<tr>
<th>Theme identified in Flood Inquiry Report</th>
<th>Private approaches to resilience policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dams monitored in Queensland</td>
<td>2 (a) At private (farmer) cost upgrade and maintain dams under command and control (direct) regulation</td>
</tr>
<tr>
<td>Focus is on referable dams. (106, 85 of which have been subject of a dam safety audit since 2007)</td>
<td>Not addressed</td>
</tr>
<tr>
<td>Scope of investigation</td>
<td>&quot;The Commission’s investigations have so far only involved referable dams.&quot;</td>
</tr>
<tr>
<td>Flood mitigation through catchment/ floodplain management</td>
<td>&quot;The Commission’s investigations have so far only involved referable dams.&quot;</td>
</tr>
<tr>
<td>Development considerations</td>
<td>&quot;The Commission’s investigations have so far only involved referable dams.&quot;</td>
</tr>
<tr>
<td>Toowoomba Regional Council and the Department of Environment and Resource Management should continue to cooperate to assess the referable dam status of existing detention basins and any future detention basins constructed in the West Creek and East Creek catchment areas</td>
<td>Not addressed</td>
</tr>
</tbody>
</table>

6. Development of a resilience policy for cumulative flood risk

It is evident from the above review of the Queensland Floods Inquiry that there is a failure to address nearly all elements of resilience policy identified for private dam flood safety impacts. The range of approaches derived in Section 4 and considered in Tables 3a and 3b could in fact also be combined to form a public-private partnerships approach (i.e. Approach 4) which would involve a combination of Approaches 1 to 3. Considering such a combined approach clearly has scope for future research. In order for downstream communities, ecosystems and business to have resilience to cumulative flood impacts transferred from private to public dams, there is a need for planners, decision and policy makers to realise multiple approaches to resilience (Linnenluecke & Griffiths 2012). Resilience to cumulative flood impacts involves not only policy robustness (how strong
policies are to prevent private dam failure cascading to public dams), but also rapidity (effective implementation of policy) (Linnenluecke & Griffiths 2012). When these two elements of resilience policy are addressed, then policy makers can take steps towards implementing the best approach to managing the increased number of private dams under increased development and their potential for failure.

6.1 Robust resilience policy – the importance of insurance

The approaches derived from international review show that there are jurisdictions world-wide that recognise the need for resilience throughout a catchment. All of the elements under the approaches can be included in robust resilience policy which would provide the most resilience to communities. But theoretically it is possible to incorporate even some of the elements into robust resilience policy (see Tingey-Holyoak et al. 2011). Direct regulation of private dams supplemented by other elements of resilience, especially insurance methods, can provide an approach to resilience that offers a remedy against any unavoidable risk, (Knight 1921) and allows insurance providers (either insurance companies or government) to contribute a quasi-regulatory form of supervision of dam owners’ safety management practices and standards, in effect supplementing and reinforcing the supervision provided through the dam safety regulator, which can often be limited due to insufficient staffing and resourcing (see Pisaniello et al. 2012).

Information about and encouragement for private dam owners and communities to obtain insurance can be beneficial and is one way that the issue can be approached. However, requiring by law that private dam owners and/or downstream communities that could be impacted by dam failure floods have insurance to cover them for all the consequences in the event of dam failure would considerably strengthen this approach. This is a form of resilience that works on the ‘recovery’ definition as it provides more of a remedy once dam failure has occurred rather than assurance that dams are being managed properly so that private dam failure risk transferred to public dams is minimised to an acceptable level. This method can provide a quasi-regulatory form of supervision of dam safety management when insurance premiums are linked to the level of dam safety management being provided for dams. That is, if dams are not managed to an acceptable standard by owners, insurance premiums will be significantly higher. This approach would allow for the insurance market to set the premiums, that is, insurance companies would require dams to meet best practice standards and have plans and mechanisms in place in line with current acceptable standards otherwise premiums would be extremely high. The problem with this approach at present is the lack of availability of affordable insurance for small dam owners (FEMA 2009; Davies 2001). Hence, in order to mandate dam owners to purchase dam safety/failure insurance, government would need to consider providing
some form of subsidisation scheme to assist with premium affordability—especially if private dam owner outrage is to be avoided.

Despite the beneficial role of insurance mechanisms for resilience policy, there is little involvement of the industry, even in an area with increased attention to dam management policy like the Wivenhoe catchment after recent floods. Even though insurance industry involvement in serious private dam failure or crisis could be considerable, there is immaterial evidence of involvement in individual or cumulative private dam risks and uncertainty. For example, if a dam is managed unsustainably then it poses an economic risk to the community, ecosystems and to business operations. Despite weather events in the country demonstrating increasing severity, insurance company and mortgage provider private dam caveats do not appear to be a substantial part of the institutional environment to create resilience in the face of the risk posted by cumulative dam failure flood but are recommended here.

6.2 Rapidity of resilience policy – a tool to account for optimal private dam protection in the face of cumulative flood risks

For resilience to be effective, resilience policy must be able to be enacted efficiently to enable communities to be at reduced risk as soon as possible. Accounting for flood risk through technology can complement the type of resilience policy identified in Section 6.1 containing both command and control and insurance mechanisms. The technological accounting tool developed by Pisaniello et al. (2012) based on best practice catchment analysis, calibration and modelling, flood hydrology and reservoir hydraulics, all in line with IEAust (1999) provides an example of a possible mechanism to create rapid implementation of resilience policy. The resilience policy tool allows for accounting for the hydraulic response of any size of reservoir and spillway(s) relative to the hydrological flood response of the selected rural catchment in an ‘hydrologically homogenous’ region for the full range of design storm events up to the Probable Maximum Precipitation (i.e. 1 in 10,000,000 years Annual Exceedence Probability (AEP)). This accounting tool has been developed in South Australia, Victoria and New South Wales (Pisaniello & McKay 2007) in order to promote consistency and uniform standards in the design and review of private dams.

Practical application of the rapid accounting tool technology involves using a regionalised relationship based on simple hydrological/hydraulic variables, for predicting reservoir flood capability – known as Dam Crest Flood (DCF) (see Pisaniello et al. 2012). The procedure is applicable to reservoirs on small rural-type catchments (up to approximately 25 km²), is compatible with any design flood standards, and is based only on easily derived variables, (i.e. spillway width and height, reservoir area, catchment area), deeming it quick to use yet accurate in the output it
provides. ANCOLD (2000a) ‘fallback’ acceptable flood capacity criteria ranges have been incorporated for different hazard category dams. The hazard category for a dam can be determined using ANCOLD (2000b) and the tool can be made available as a fast to use, simple on-line spreadsheet for undertaking this hazard assessment process in line with ANCOLD (2000b).

7. Discussion and conclusions

The research question, what range of elements of resilience policy can be adopted for the management of private and public catchment dams to prevent future cumulative flood threats to communities under conditions of increasing risk and more frequent and/or severe extreme weather events? has been answered in two ways: (1) understanding the risks to resilience of communities posed by transfer of flood risk from private to public dams is increased through reviews of surrounding literature, in addition to identification of the elements of private dam management resilience policy for cumulative private dam failure risk; and (2) through case study analysis of Wivenhoe catchment, which despite recent catastrophic flood disaster does not consider most critical elements of resilience policy in decision making, the potential for cumulative private dam flood failure transference to occur under future more extreme rainfall events is highlighted.

Answering of the research question provided a foundation for the development of preliminary guidelines to emerge for robust and rapid private dam management resilience policy that includes elements of (1) insurance mechanisms to compliment and strengthen command and control regulation; and (2) an accounting tool to facilitate rapidity and ease of implementation of resilience policy. In addition, the possibility for a fourth ‘approach’ to resilience policy emerged from the review that considers combining a selection of the public-private approaches to form an optimal partnership of mechanisms, which is the scope of future research.

Ultimately, the research here draws awareness to the challenge for communities downstream of public dams in catchments of private dams where there is little or no resilience policy to deal with the risk, especially when faced with ever increasing weather related disasters. However, what is also highlighted is the need for an urgent future research agenda that includes gathering evidence on the extent of the private dam failure problem in Wivenhoe catchment in the 2011 floods, in addition to key farming, government, community, environmental group and insurance industry stakeholder perception, attitude and behaviour surveys.

The paper contributes to the dam, catchment planning, and land use policy literature but also to the emerging resilience policy literature, especially as
it relates to resilience of communities to risk associated with weather-related disasters, increasingly impacted by climate change.

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