Flood management in a changing climate

by

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Candidate's Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Caroline Elizabeth Balean Wenger   Date:

Preface

This thesis is comprised of seven inter-related papers that at the time of submission were either published or in advanced review. As each paper has been designed so that it can be read separately, there is some unavoidable repetition between papers, particularly where it concerns background and case study descriptions.

In line with the ANU procedure for thesis by compilation, this thesis includes an introduction, linking text and a conclusion. The introduction is not intended to be a complete literature review, but it introduces the field of study and the theoretical and methodological context. It also provides a framework for understanding how publications fit together to address research questions. Each paper is introduced by a foreword to explain its relationship to other thesis components. The conclusion evaluates the contribution of the publications as a whole to the field of research.

The thesis uses the last submitted version and formatting has been made consistent throughout. Pdfs of the first page (publication format) are provided in Appendix 1. A consolidated list of references is located at the end, as for a standard thesis. In some cases this has required amendment of the in-text citation, i.e., where different publications use more than one citation by the same author in the same year, e.g., (Author, 2001*a*), (Author, 2001*b*), the identifying letter sometimes needed changing to ensure it referred to the correct reference in the compiled list. For the same reason, the author name has sometimes been modified from the published version. For example, the author name may have been written MRC in the published version but this may have referred to Maranoa Regional Council in one publication and the Mississippi River Commission in another. To avoid confusion, the citation in such cases has been written out in full. For reasons of clarity I have chosen to retain the formatting of the first submitted version of Publication 7 for tables S.7.1, S.7.2 and S.7.3. Journal specifications did not allow the use of lines nor colour coding in tables. This is a format, not a substance change.

Publications

Publication drafts benefitted from the feedback of my supervisory panel: Jamie Pittock, Katherine Daniell, Michael Eburn and Steve Dovers (adviser). The title, authorship, publication outlet and current status of each publication, as well as the extent of my contribution to the research of multiple authored papers are as follows:

Publication 1

Wenger, C, Hussey, K, Pittock, J, 2013, 'Living with floods: key lessons from four Australian flood reviews and similar reviews from the Netherlands, China and the USA', 53rd Floodplain

Management Association Conference, Tweed Heads, 28 - 31 May 2013, pp. 13. The Floodplain Management Association published the paper online at:

http://www.floodplainconference.com/papers2013/Jamie%20Pittock%20Full%20Paper.pdf

This is a synopsis of the 'Living with Floods' project report (see publication 2). The project proposal was prepared by Jamie Pittock. Karen Hussey obtained funding and along with Jamie, acted as supervisor. Caroline Wenger collected the data, determined analysis methods, analysed and interpreted data, wrote the report and the conference paper and revised according to supervisor and peer-review comments.

Publication 2

Wenger, C, Hussey, K, Pittock, J, 2013, 'Living with floods: Key lessons from Australia and abroad', National Climate Change Adaptation Research Facility, Gold Coast, pp.264. ISBN: 978-1-921609-89-3. The National Climate Change Adaptation Research Facility published the document online at:

https://www.nccarf.edu.au/sites/default/files/attached_files_publications/Wenger_2013_Living_with_floods.pdf

A limited print run was subsequently produced in 2014, for key stakeholders (government agencies and state libraries) incorporating minor revisions.

The project proposal was prepared by Jamie Pittock. Karen Hussey obtained funding and along with Jamie, acted as supervisor. Caroline Wenger collected the data, determined analysis methods, analysed and interpreted data, wrote the report and revised according to supervisor and peer-review comments. Publication 2 (Netherlands case study) is an extract of this report. Prof dr A.J.M. Smits Institute for Science, Innovation & Society, Nijmegen, NL provided feedback on the draft of Publication 2.

Publication 3

Wenger, C, 2013, Climate change adaptation and floods: Australia's institutional arrangements, National Climate Change Adaptation Research Facility, Gold Coast, pp. 65. ISBN: 978-1-925039-92-4. Published on the National Climate Change Adaptation Research Facility website at:

https://www.nccarf.edu.au/sites/default/files/attached_files_publications/Wenger_2013_Case_study.pdf

This is one of seven case studies contributing to a broader NCCARF project: "Statutory frameworks, institutions and policy processes for climate adaptation". Publication 3 conforms to project methodology (designed by Steve Dovers, Karen Hussey and Richard Price). Caroline Wenger researched and wrote the paper.

Publication 4

Wenger, C. 2014. 'Sink or Swim: alternative approaches to flood disaster reconstruction and mitigation', in *River Basin Management in the Twenty-First Century: understanding people and place,* (V. Squires, H. Milner and K. Daniell, eds), CRC Press, Boca Raton, Florida, pp. 418-445. ISBN: 978-1-4665-7962-0.

Publication 5

Wenger, C. 2015. Better use and management of levees: reducing flood risk in a changing climate. Environmental Reviews, 23(2), pp. 240-255. doi: 10.1139/er-2014-0060.

Publication 6

Wenger, C. 2015. Building walls around flood problems: the place of levees in Australian flood management, Australian Journal of Water Resources, 19(1), pp. 3-30, doi:10.7158/W15-008.2015.19.1

Publication 7

Wenger, C. [under review]. The oak or the reed: how resilience theories are translated into disaster policies. *Ecology and Society*. Has been resubmitted following minor comments: submission number ES-2016-8425.

Addendum: since this thesis was submitted for examination, publication 7 has been accepted with minor amendments. Two of the supplementary documents (1 and 3) have been published separately as a technical report, available at:

https://www.bnhcrc.com.au/publications/biblio/bnh-3570

Acknowledgements

My research into flooding began with a phone call: “Caroline, how would you like to come and do some research for me?” It was my former boss, Jamie Pittock. Coincidentally, my contract at the National Water Commission was almost at an end, so with some trepidation (my Honours thesis seemed a long way away), I started work on a project funded by the National Climate Change Adaptation Research Facility (NCCARF) with Jamie and Karen Hussey. It turned out I was not as rusty as I’d feared and before long it was suggested that I should extend my work and transform it into a PhD. So my biggest acknowledgement is to Jamie for believing I could do it and for giving me the opportunity and support that allowed me to keep going.

I am also very grateful to my other supervisors. Karen Hussey supervised my initial work and was very encouraging. Michael Eburn, Katherine Daniell and Steve Dovers (adviser) have also been extremely supportive, reading drafts, offering me advice about publishing, informing me of opportunities and hosting a support network of PhD students. I am also grateful to ANU’s Fenner School of Environment and Society staff, including Clive Hilliker for great graphics assistance, to Katrina Proust for advice on influence diagrams and to other professional and academic staff including Cathy Gray, Dianne Jackobasch, Kevin Mahony, Amy Chen, Jack Pezzey and the IT team.

Research has benefitted greatly from funding and research presentation opportunities offered by NCCARF and the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC). My BNHCRC scholarship has been much more than just financial and I recommend the CRC to any student who might initially feel wary about research independence or have IP concerns. The CRC has been infinitely supportive and has provided networking and research communication opportunities with both industry and other researchers at their annual conference, research advisory forums, through ‘hazard notes’, student development days and other events. The experience has been extremely rewarding and I am very grateful to BNHCRC’s Michael Rumsewicz, Lyndsey Wright, Vaia Smirneos, Nathan Maddock and David Bruce.

It’s traditional to thank your family for bearing with you during the ups and downs and in view of the massive support I received from my husband Eric and daughters Lucy and Melia, I will not break with this tradition. Thank you! Thanks also for proof reading my drafts and for being my guinea pig audience. Thanks to my parents and their parents, for my father and grandfather’s love of logic, science and obsession with detail, for my mother’s visual and literary skills, for Granny B’s love of nature, and Granny C’s dramatic ability and to A.J. for her energy and courage. While most of them are no longer with me I have felt them flow into my work.

Finally, my friends and fellow PhD students have been a huge support and great fun along the way. Kat Ng – without you to drag me out of the office I'd be hunched as a limpet. Peter Ramshaw, Sue Hunt, Monique Retamal, Helen King and the rest of the gang in our write up wing, Jann Ollerenshaw and my diving friends and Ruth Flower: thanks to you all for discussions, laughs, social occasions and for lightening the road.

Abstract

In 2010-2011 Australia experienced its most expensive floods in history with costs to insurers and state and federal governments exceeding A$10 billion. Climate and population changes are likely to increase future flood threats and economists estimate that by 2050, even without factoring in climate change, Australia's natural disaster damage bill could reach $33 billion per year. Flood management is thus a key area for improving adaptive capacity.

While the causes of flooding are well-known, effective solutions have proved elusive and some flood management options may be maladaptive in the longer term. There were contradictions in flood management literature. Some sources categorized structural measures such as dykes and levees as adaptation measures. Others warned about their negative impacts. Meanwhile, innovative approaches used overseas appeared little known or used in Australia.

Although structural measures were often criticized in adaptation literature, there was a lack of guidance about *how* to reduce reliance on them. Similarly, resilience researchers with a social-ecological systems perspective argued the need to identify policy and institutional interventions that would make it possible to move from undesirable to more desirable resilience domains.

The challenge was therefore to determine *how best to adapt* to increasing flood risk, and *how to facilitate the adoption* of adaptive approaches. A key question was whether adaptive approaches used elsewhere were transferrable to Australia. Given the dominance of resilience theory in modern disaster management, a related research aim was to determine whether or not disaster resilience policy was likely to achieve adaptive outcomes.

Literature review was the primary research method, supplemented with semi-structured interviews. Sources included recent flood reviews, academic literature, policy and legal documents. These were used to develop comparative case studies from China, The Netherlands, the United States and Australia. This was extended to cover global organizations for the resilience component of the work. Data analysis drew on literature relating to adaptation, resilience, comparative public policy, institutional theory and emergency management. Resilience interpretations were identified in a systematic way using a modified emergency management framework, complemented with narratives.

Results revealed that resilience interpretations varied according to country, with Australia tending to be the least adaptive and the Netherlands the most. This reflects changes in attitudes towards structural mitigation. While support for structural mitigation remains strong in Australia, recent flood events in other countries have exposed its weaknesses. This has resulted in a shift to reduce levee dependency, accompanied by support for alternatives such as

ecosystem based measures and development relocation. Such measures encounter significant barriers in Australia, making policy transfer problematic. Nevertheless, case studies revealed opportunities to improve program implementation, and investigation of path dependency associated with structural mitigation identified opportunities to alter feedbacks. Regarding application of resilience theory to disaster management, it was found that while resilience is a useful concept for researchers, there are problems when it is operationalised. A better focus for practitioners would be to negotiate long-term adaptation pathways.

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Publication 3

Introduction

1. Rising Flood Damages

Flooding is Australia's most expensive natural hazard and has been a problem since early settlement. The Federal Government reported that between 1967 and 2005, average annual flood damage costs were $124.5 million[1] for Queensland; $40.2 million for Victoria and $376.9 million Australia-wide. The average cost across all natural hazards was $1.2 billion per annum (BITRE 2008). In 2010-2011, Australia experienced its most expensive flood disaster in history. The cost of rebuilding public infrastructure was estimated at $6.8 billion for Queensland alone, while state and federal costs for Victoria totalled $0.971 billion (Comrie 2011; QFCI 2011; QRA 2011*a*; VAGO 2013). The cost to private insurers was $2.5 billion (ICA 2013). Figures do not cover uninsured and indirect losses.

Future damages are expected to rise still further. Deloitte Access Economics anticipates that by 2050 damage costs across all natural hazards could reach $23 billion per year, even without factoring in the effect of climate change (DAE 2013). If indirect costs are incorporated, this figure could reach $33 billion per year (DAE 2016). Australian experiences are not unique. The number and scale of natural disasters and associated financial losses have risen globally. The greatest increase can be attributed to meteorological and hydrological events including storms and floods (Jha *et al.* 2012; Munich RE 2013).

The reasons disaster costs are rising are well understood. Population increase and pressure for land, movement of vulnerable groups such as retirees to vulnerable areas, and increasing material wealth all contribute to increasing exposure to floods and associated damages (White et al. 2001; DCC 2009). At the same time, continuing floodplain encroachment has reduced the natural ability of the landscape to absorb and store floodwaters. Reduced floodplain connectivity, wetland destruction, vegetation clearance, levees and efficient urban drainage funnel water quickly into waterways. This increases its flood depth and velocity and decreases warning times (Jones 2000; MEA 2005; Tockner et al. 2008).

Climate change magnifies risks. It is expected to increase the severity and likelihood of floods in Australia and globally, though impacts are less clear at the individual basin scale (Christensen *et al.* 2007; Bates *et al.* 2008; Milly *et al.* 2008; IPCC 2013; Arnell and Gosling 2016). The difficulty of distinguishing natural climate variation from human induced climate change contributes to the uncertainty surrounding future flood threats. Natural cycles play out over decades, or even multiple decades. In the southern hemisphere, one of the most significant of these is the

[1] Given in 2005 Australian dollar values.

interaction between the El Niño-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) (Verdon *et al.* 2004). Such long-term variations demonstrate why it can be hard to determine how much observable change is due to natural variation that plays out over long time scales, and how much is due to increased greenhouse gas emissions.

Despite debate about whether recent increases in flooding can be attributed to natural climatic variation or anthropogenic causes, some climatologists claim they have evidence demonstrating that anthropogenic climate change has caused increasingly intense precipitation events in the United Kingdom (Min *et al.* 2011; Pall *et al.* 2011). The severity of 2010-11 floods in Australia has also been linked to climate change, with abnormally elevated sea surface temperatures increasing the total rainfall over Australia by up to 25% and coinciding with a measurable decline in ocean mass (Boening *et al.* 2012; Evans and Boyer-Souchet 2012; Fasullo *et al.* 2013). A recent multi-model analysis of flood risks in major global river basins suggests that Australia's Murray-Darling Basin is likely to be one of the worst affected by climate change. A twentieth century 1 in 100 AEP[2] flood may occur, on average, every ten years before the end of the 21st century (Hirabayashi *et al.* 2013). Dirmeyer *et al*. (2016) modelled soil moisture, precipitation and runoff up until 2100 to investigate permanent departure of water cycle parameters from the historical mean. Results for Australia suggest that during this period there will be permanently increased dry conditions in winter and greater runoff in summer over much of the east.

The effect of climate change on inland flooding is likely to be variable over time and between catchments (Bates *et al.* 2008; State of Queensland 2010). There is greater certainty about the effect of climate change on sea level rise (SLR). SLR is a serious issue for Australia as settlement is concentrated along coastal fringes. A national risk assessment found that SLR of 1.1 m could potentially expose more than $226 billion of Australian coastal assets to flooding and erosion (Australian Government 2011*a*). If average global temperatures rise between one and two degrees Celsius, the number of Australians exposed to risk of flooding may double (Preston and Jones 2006; Australian Government 2011*a*).

While the causes of flooding are well known, there has been an inability to put in place effective solutions. Following Australia's 2010-11 floods, the IPCC found that Australia had a 'significant adaptation deficit in some regions to current flood risk' (IPCC 2014). With threats expected to worsen, there is a risk that badly-planned, reactive responses to flooding will be implemented that may prove maladaptive in the long term. Decision makers need to focus on approaches and activities most likely to minimise future flood damages. The challenge is therefore to

[2] Annual exceedance probability (AEP) is the probability of exceedance of a given discharge within a period of one year (Engineers Australia, 2015). For example, a discharge that has a probability of being exceeded once every 20 years (1 in 20 AEP) has a 5% probability of being exceeded in any given year (5% AEP).

determine *how best to adapt* and *how to facilitate the adoption* of adaptive approaches. This entails study not only of different alternatives to managing floods, but also the institutional arrangements that might help or hinder adoption. Accordingly, the following overarching research questions and sub-questions will be addressed:

Research Questions

Which approaches to flood management are most likely to maximise the capacity to deal with anticipated changes in climate and population?

- *Are innovative approaches that appear to be adaptive overseas transferrable to Australia?*
- *What barriers need to be overcome and which reforms would be necessary to implement measures and approaches with the greatest adaptive potential?*

Is the current 'resilience' paradigm, popular in many parts of the world, adequate to address future flood threats?

- *What are its strengths and weaknesses?*
- *If it needs to be replaced, what does it need to be replaced by?*

To answer these questions, investigations drew on many theoretical fields including comparative public policy, institutional design, adaptive management and the concept of resilience.

2. Emergency Management Frameworks and Concepts

Australian emergency management is guided by a number of frameworks and concepts. One of the most enduring is the "Prevention-Preparation-Response-Recovery" framework, or PPRR (EMA 2004). Mitigation is often combined with prevention in recognition that 'prevention' of floods is unrealistic (e.g., COAG 2014). The framework was first developed in the USA in 1978, where it is also known as Comprehensive Emergency Management. It represents an attempt to better integrate *ad hoc* mitigation and long-term recovery programs and agencies into operational response (NGA 1979; Crondstedt 2002).

PPRR provides a useful categorization of different flood management options and management stages that can be applied on a cyclical timescale: before, during and after a disaster. However, it has been criticized for failing to incorporate anticipation and assessment; for creating an artificial barriers between different emergency management phases; and for appearing to give equal weight to different flood management treatments (Crondstedt 2002; Rogers 2011).

More recently, PPRR has been augmented by other concepts. Chief among these are resilience and its twin concept, shared responsibility. These concepts are promoted globally by the United

Nations International Strategy for Disaster Reduction (UNISDR) Hyogo Framework (UNISDR 2005). In Australia, resilience has become a guiding concept for disaster management through the National Strategy for Disaster Resilience and associated programs (COAG 2009; COAG 2011). It supports the contemporary flood risk management approach through improved flood risk information, as well as greater public availability of information to enable shared responsibility for risks.

Resilience has a history of transfer across different disciplines, from engineering to psychology and ecology (Alexander 2013). When interpreting resilience in the context of disaster management, researchers have drawn on all these fields and this has resulted in a multitude of disaster resilience definitions (Norris *et al.* 2008; Liao 2012). Some of these focus on distinct geographic or social entities, such as cities, communities or individuals. Other definitions focus on the persistence of complex systems, and are more broadly applicable to the way in which human institutions and power structures are intertwined with hazards.

Initial research into Australian emergency management arrangements yielded an intriguing resilience definition in Australia's National Partnership Agreement on Natural Disaster:

> the capacity to prevent/mitigate, prepare for, respond to and recover from the impacts of disasters
>
> (COAG 2009: Schedule A)

This definition, given in terms of PPRR, raised some interesting questions about the relationship between resilience and pre-existing emergency management frameworks. For example, was resilience merely a re-invention of PPRR? If resilience was interpreted through PPRR how did this influence implementation? Was the 'PPRR-Resilience' relationship confined to a single Australian legal document or was there evidence of it elsewhere. Further research suggested this was a gap in the literature that merited investigation.

It was unclear from a review of the literature about how useful resilience was as an emergency management concept. Supporters argue that resilience indicators can provide a pathway to improved resilience (Cutter *et al.* 2008; Sudmeier *et al.* 2013; Cutter *et al.* 2014; Parsons *et al.* 2016). Resilience policies reflect global trends to decentralize disaster management to sub-national and local levels of government (Lal *et al.* 2012). With its positive message, resilience can be used to empower rather than victimize those living in hazard prone areas (Klein *et al.* 2003; Reghezza-Zitt *et al.* 2012). Moreover, with more severe and frequent disasters on the horizon, and emergency services more likely to be overwhelmed, promoting self-sufficiency seems a logical policy choice (Wenger *et al.* 2013).

However, resilience also has many detractors. For example, according to Park (2011) resilience is a buzzword: "seductive, sounding good when you say it while remaining ambiguous and open to multiple interpretations". He suggests it is partially redundant to older concepts such as adaptability. Some authors see parallels between resilience and neoliberalism, whereby people are encouraged to self-organise rather than be controlled in a disaster, which could be a positive (Zebrowski 2013). However, with this comes the danger of governments failing to address underlying causes, shifting responsibility onto local communities and blaming those who fail to participate (Hornborg 2009; Reghezza-Zitt *et al.* 2012; Sudmeier-Rieux 2014). Moreover, the efficacy of community preparedness programs is questionable (Paton and Johnston 2001). There are also issues in determining what makes a community resilient. Abundant research has been carried out to measure resilience (e.g., Cutter *et al.* 2014; ISO 2014; Parsons *et al.* 2016). Yet exhaustive lists of indicators may not predict outcomes for systems characterized by complexity. 'The proof of the pudding is in the eating' and it is hard to judge resilience until after an event has happened. Even then, there are political and technical issues about who judges resilience and why, of which social groups, over what timescale, area, event type and magnitude. There is also conflict within resilience definitions, between the need for remaining the same and the need to adapt (how much adaptation will cause a system to change), the expectation in some resilience definitions that a system should aim for stability, versus the observation that exposure and vulnerability (instability) are pre-requisites or partners in developing resilience to hazards (Klein *et al.* 2003; Reghezza-Zitt *et al.* 2012; Lewis 2013; Sudmeier-Rieux 2014).

Applied to disaster management, resilience therefore appears to have both positives and negatives. A significant concern is that 'resilience' is not consistently defined (McAslan 2010; Alexander 2013). This lack of focus could lead to variable implementation and outcomes that are not truly adaptive in the longer term.

Resilience can be characterized as a process (continuous, open-ended adjustment), or a property (a state of resilience: an outcome) (Norris *et al.* 2008; Reghezza-Zitt *et al.* 2012). While most prefer to view resilience as a process, outcomes need to be considered once resilience is operationalized. Much work has been done on conceptualising resilience, measuring resilience and identifying its uses and abuses. However, there is a lack of empirical research on how resilience has been implemented and, in particular, whether it is likely to lead to outcomes that would be adaptive over the longer term, a key concern of this thesis. A critical appraisal of resilience was therefore undertaken to determine its usefulness as a guiding concept for government policy and its adequacy in the face of future challenges.

3. Identifying adaptive approaches to flooding

Modern floodplain management originated with the work of Gilbert F. White (1945), who divided floodplain management measures into structural and non-structural. *Structural* (or 'hard') measures comprise engineering solutions such as levees, dams, floodwalls, detention basins and channel straightening. This was the dominant approach prior to White's work. Structural approaches are often the preferred option for protecting existing development due to perceived savings in avoided damages and because they are viewed as economical (BTRE 2002; Cutter *et al.* 2012; Wong *et al.* 2014).

However, infrastructure can have significant negative impacts and can increase potential damages (Smith 1998; Burby 2006; IPCC 2012). *Non-structural* (or 'soft') measures relate to managing flooding through land use planning, building codes, legal frameworks, warning systems, emergency planning, education and insurance (White 1945). Research by White pointed to the considerable benefits of taking a more non-structural approach, particularly by adjusting land use in floodable areas, based on flood studies and supported by regulations and zoning. In the 1950s the Tennessee Valley Authority decided to implement an experimental program based on White's ideas (Wright 2000). Its outstanding success in saving lives, property and in reducing expenditure on disaster recovery and structural mitigation was instrumental to the subsequent integration of non-structural approaches nationally in the USA, and later internationally.

More recently, a third category has been added that aims to enhance the landscape's natural ability to absorb and mitigate flooding (Freitag *et al.* 2009; Jones *et al.* 2012). Known as the '*ecosystems based approach*', or the '*natural assets approach*', its aim is to increase flood storage and water infiltration, thereby reducing and delaying runoff. Ecosystems based approaches are also used to address flood issues relating to sediment and erosion.

Structural, non-structural and ecosystem-based approaches are associated with specific measures but they are not universally applicable and local context needs to be considered when selecting which to use. For example, ecosystems approaches often depend on land being available for implementation, while large urban centres such as New Orleans that are historically dependent on flood levees would find it virtually impossible to abandon structural flood defences. Flood warnings may be of high importance to communities in narrow catchments prone to flash flooding but of less importance where large, flat catchments mean that a flood takes two weeks to arrive. Despite these differences, it is important for this analysis to determine in general terms which approaches and measures appear to have the most and the least adaptive potential. Initial research suggests that ecosystems approaches have significant adaptive potential. While used overseas as an adaptation measure to address climate change, they appear to be little understood in Australia. Studying the use of such measures overseas and the factors which might facilitate or prevent their application in Australia was explored in this work.

The threat of climate change has seen a strong push towards the idea that societies will need to improve their capacity to adapt to inevitable changes (Adger *et al.* 2005). For flood hazard, we need to adapt not only to projected changes in climate but to the consequences of our past and future settlement decisions and landscape modifications. However, there are conflicting views about what constitutes an 'adaptive' measure. In its AR4 synthesis report, the Intergovernmental Panel on Climate Change (IPCC), one of the world's most authoritative international climate change organisations, defined adaptation as:

> Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones, etc.
>
> (IPCC 2007*b*: 76)

The 2007 IPCC report was current at the time literature was being reviewed to determine thesis research priorities. Its definition specifically includes the construction of dykes / levees as an example of an adaptive measure. These measures are also included in the United Nations Framework Convention on Climate Change (UNFCCC) report on technologies for climate change adaptation (UNFCCC 2006) and the Hyogo Framework, which lists 'construction of hazard-resistant and protective structures and infrastructure' among its key activities to reduce underlying risks (UNISDR 2005). This was reiterated in 'priority 3' of the Sendai Framework (UNISDR 2015*c*). Adaptation planning and funding by governments, multilateral organisations and businesses also strongly favour structural solutions (Jones *et al.* 2012; Suncorp 2012).

The IPCC AR5 report was published in 2014 and although its glossary definition no longer includes examples of adaptation measures, the main body of the report continues to recognise structural defences as an adaptation measure that sits under three broad adaptation strategies: protection, accommodation and retreat. Protection includes structural defences as well as other types of protection, including beach nourishment and vegetation (IPCC 2014).

Many sources, including the IPCC SREX report (IPCC 2012) simultaneously warn of the negative impacts of such measures (Cardona *et al.* 2012; Lavell *et al.* 2012), suggesting that such measures are not truly adaptive. Exploring this contradiction further was a significant aspect of this research.

For the purposes of this research, the IPCC SREX report definition of adaptation was used as it makes no value judgement about the merits of individual measures:

> the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities
>
> (IPCC 2012: 556)

Maladaptation is the flip-side of adaptation and can be defined as:

> action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups
>
> (Barnett and O'Neill 2010: 211)

Cross-sectoral and social linkages are notable in this definition, showing the importance of identifying positive and negative externalities of proposed adaptation options. The authors identify five categories of maladaptation: increasing GHG emissions; path dependency; high economic, social or environmental costs (compared with other alternatives); reduced incentives to adapt; and measures that place a disproportionate burden on the most vulnerable. In later work, Barnett and O'Neill (2013), suggest that the risk of maladaptation is greatest for high cost exposure reduction (e.g., compulsory, large-scale resettlement; structural protection). Risk is lower where the aim is to reduce sensitivity to hazards (e.g., building codes; managed retreat) and lowest where the aim is to increase adaptive capacity (e.g., access to information and financial resources to fund adaptation).

A common concern for adaptation theorists is the integration between different sectors and social groups, so that a seemingly positive adaptation by one does not adversely impact another (Adger *et al.* 2005; Hallegatte 2009; Cork *et al.* 2010; Eriksen *et al.* 2011). Adger *et al*. (2005) noted that effective adaptation depends on flexibility, robustness to uncertainty and the use of long term planning scales and broad spatial scales. Economic efficiency, equity and social acceptability also influence the success of adaptation.

Hallegatte's adaptation ranking system is largely based on the problem of uncertainty (Hallegatte 2009). He notes that in some areas it will be another 40 years before changes in precipitation patterns due to GHG become statistically detectable and distinguishable from natural variation where different patterns interact over many decades. It is a mistake to wait so long for modelling to be fully validated, as by that time a maladaptive decision may have been made. Moreover, projection ranges continue to be large despite improved information, and future models are unlikely to yield the degree of certainty that planners require.

Hallegatte argues that it is *current decision-making frameworks* that need to be changed to accommodate this uncertainty, rather than delaying action until information provides certainty.

He ranks adaptation options according to a number of characteristics, including no-regrets strategies, reversibility, ease of incorporating low-cost safety margins, soft strategies (which by their nature are generally reversible), avoiding long-term commitment (uncertainties increase further into the future) and synergies, which consider externalities to other sectors. ‘Institutionalisation of a long-term planning horizon’ is an example of a soft management measure that forces planners to look several decades ahead. Other high-priority measures relevant to flood management include climate-proofing new building and infrastructure, restrictive land use planning, insurance and the development of early warning systems and evacuation systems. Structural solutions and options such as relocation and retreat were less favoured, as they are not reversible or flexible (Hallegatte 2009). Adaptive and maladaptive characteristics identified by Adger *et al*. (2005), Hallegatte (2009) and Barnett and O’Neill (2010) were used to identify flood management options with the most and least adaptive potential. They also informed analysis of the use of different measures in the Australian context.

4. Transferring adaptive approaches

It is not sufficient merely to identify adaptive approaches; there also needs to be uptake of ideas. Institutions as well as practices need to be adaptive. Cork *et al.* (2010) suggest four characteristics can be used to determine whether or not institutions are adaptive: clarity of purpose; the diversity of options for adaptation; connectivity (e.g., between researchers, policymakers and stakeholders); integration and feedback. Dovers (2001) provides a more specific description of adaptive institutions, comprising of five key principles and fifteen attributes that enable them to learn and improve over time. Among these, Dovers includes the ability of institutions to conduct comparative analysis and to experiment with approaches and methods.

The transfer of desirable policies in use elsewhere is the subject of a huge body of literature. According to Rose (2005), programs are subject to inertia as it requires effort to proactively look for optimal alternatives when there is nothing apparently wrong with what is already in place. However, maintaining the status quo is no longer an option when programs fail to achieve their objectives and cause ‘dissatisfaction’. While common problems tend to arise in many different countries, solutions can vary, providing a rich source of problem solutions that have the advantage of already being in use and ‘proven’ to be effective in that setting (or conversely, they provide lessons of how *not* to do it if the overseas program is ineffective). The challenge is to transfer desirable programs to a new setting where values, norms, institutional structures and resources may be different.

Rose advocates looking at the mechanics of program implementation to determine the elements that are present, absent or in need of adaptation between the program donor and receiver. As an example, he provides a model for a free and fair election, and describes the elements of the model as needing to include laws, agencies, personnel, money, program recipients, program outputs and a goal. While Rose's model incorporates some elements of institutional theory, it is firmly focused on the mechanics of the program.

In practice, many barriers to organisational learning have been observed. Particular problems have been identified for public sector learning. In a democratic system, diverse stakeholders have to be satisfied for an approach to be adopted, and there are also considerable difficulties linking organisational learning with agencies' strategic objectives and performance outcomes (Common 2004). Evans (2009) divides obstacles to policy transfer and policy-oriented learning into three interrelated categories: cognitive (processes relating to problem recognition and the search and selection of alternatives); environmental (including political, institutional, socio-economic, technical and resource constraints); and public opinion (attitudes and opinions of the élite, constituent groups, media).

As learning through comparative policy analysis is an important element of adaptive governance, it is not surprising that the barriers to policy transfer identified by Evans show striking overlap with barriers to climate change adaptation identified by other authors (Adger *et al.* 2005; Adger *et al.* 2007; Ebert *et al.* 2009; Productivity Commission 2012; Hussey *et al.* 2013; Palutikof *et al.* 2013). These authors identify many types of adaptation barrier, including regulatory structures, property rights, social norms and administrative processes (Adger *et al.* 2005); political (Ebert *et al.* 2009); financial, informational and cognitive, sociological and cultural (Adger *et al.* 2007); knowledge, financial, legislative and regulatory, communication (Palutikof *et al.* 2013); institutional, policy, financial, regulatory, information / awareness (Hussey *et al.* 2013); market based, policy and regulatory, governance and institutional, behavioural and cognitive (Productivity Commission 2012). These have been condensed into four categories of adaptation barrier in Table 1.1, below. Barriers such as these indicate close ties between policy transfer, adaptive governance and institutional theory.

Cognitive	Institutional	Political	Resources
Information / awareness	Sociological and cultural norms	Attitudes, values of the ruling élite	Technology
Problem recognition and understanding	Legislative / regulatory frameworks	Public opinion	Skilled personnel
	Market based mechanisms	Media opinion	Financial
	Governance / processes	Resulting policy	

Table 1.1: Four categories of adaptation barrier distilled from the literature review.

Institutions have been defined by many authors. Ostrom and Cox view institutions as:

> commonly understood codes of behaviour that potentially reduce uncertainty, mediate self-interest and facilitate collective action
>
> (Ostrom and Cox 2010: 454-455).

A similar but more expansive definition is provided by Handmer and Dovers (2007):

> Institutions are persistent, predictable arrangements, laws, processes or customs serving to structure transactions and relationships in a society. These transactions are political, social, cultural, economic, personal, legal and administrative. Institutions may be informal or formal, legal or customary, and in terms of function may be economic, cultural or informational, highly visible and regulatory or, alternatively, difficult to discern and relying on tacit understanding and adherence. Institutions allow organized, collective efforts around common concerns, and reduce the need for constant negotiation of expectations and behavioural contracts. Although persistent, institutions constantly evolve and adapt.
>
> (Handmer and Dovers 2007: 30)

Handmer and Dovers further explain that institutions do not operate in isolation but "within complex, interactive systems comprising multiple institutions, organisations and actors". Institutional arrangements for flooding are no exception to this. Emergency management has close interactions, for example, with natural resource dependent sectors, community health and safety and development planning systems.

Ostrom's Institutional Analysis and Development Framework (IAD) model depicts institutions as interlinked systems of information, actors, control, cost and benefit allocation, all of these being governed by formal and informal rules (Ostrom 2005). Interactions between these lead to outcomes which can subsequently be evaluated. Identifying the outcome is crucial as it provides meaning to the existence of institutions. The IAD was later supplemented with the Socio-Ecological System (SES) conceptual model, which better incorporates natural resources into the institution equation (Ostrom 2007; Ostrom 2011). The SES model could be applied to flooding, whereby the 'resource system' would be the long-term supply (and short-term *over*supply) of freshwater to catchment communities. The system's 'resource units' might be the landscape's floodwater storage and retention capacity. A high capacity would modulate flows over time, absorbing and slowing down flows in times of excess and then gradually releasing water over an extended period afterwards.

Research drew on comparative public policy and institutional theory to assess the transferability of innovative approaches from one jurisdiction to another. Following Rose (2005), flood management programs were analysed to identify the elements necessary for policy transfer. An important element of this was to identify the decision making tools and processes in place for determining which flood management options are used within flood management programs. Using Ostrom's IAD-SES model as a guide, this takes into account institutional influences to determine barriers and incentives for transfer.

5. Interlinking theoretical concepts

Literature review indicated strong linkages between resilience, PPRR, comparative public policy, institutional theory and adaptive governance. An attempt to portray this diagrammatically is shown in Figures 1.1*a*, 1.1*b*, 1.2*a* and 1.2*b*.

According to the UNISDR definition, *essential basic structures and functions* are at the core of resilience. This is the part of the system that needs preservation and restoration. The essential basic structures and functions at risk could relate to a community, a sector or to society as a whole. When exposed to shock, the essential basic structures and functions of a resilient system, need to be able to 'resist, absorb, accommodate and recover from hazards in a timely and efficient manner' (UNISDR 2009). This is shown in the high resilience model at Figure 1.2*b*.

There is disagreement between theorists about whether the system's core is in a constant state of adaptive change or whether it attempts to maintain homeostasis (discussed in Alexander 2013). This equates to Rose's *inertia* (Figure 1.1*b*), whereby systems are unlikely to change unless there is *dissatisfaction* (Rose 2005). In Figure 1.2*b*, dissatisfaction arises as a consequence of *shock*. In the context of flooding, dissatisfaction could result from the inadequate management of a major flood disaster, a 'near miss', or the foresight that conditions (environmental, social, political, economic) have changed and current management is no longer adequate.

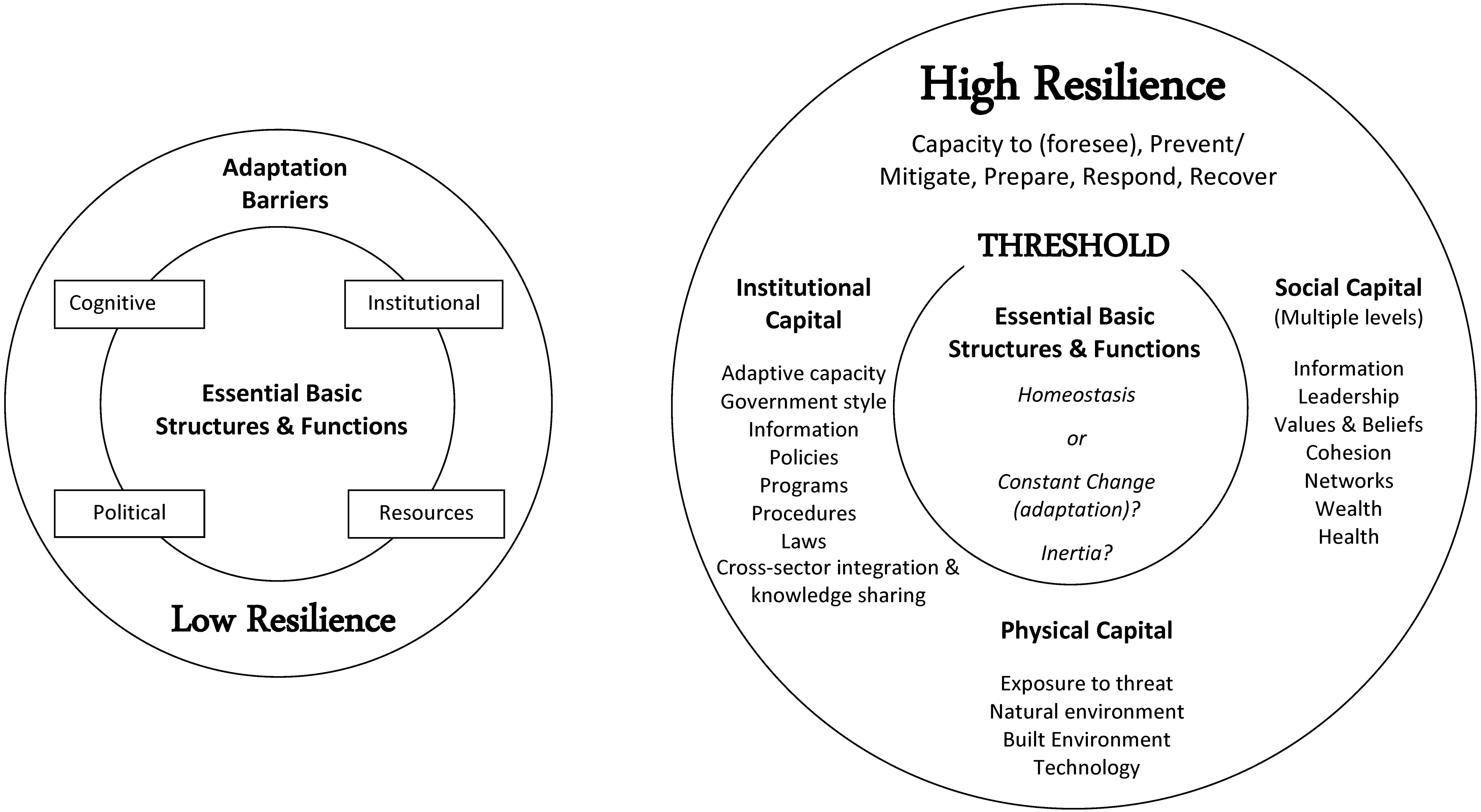

Figure 1.1: Factors influencing the level of resilience: low resilience (Figure 1.1*a*: left) and high resilience (Figure 1.1*b*: right).

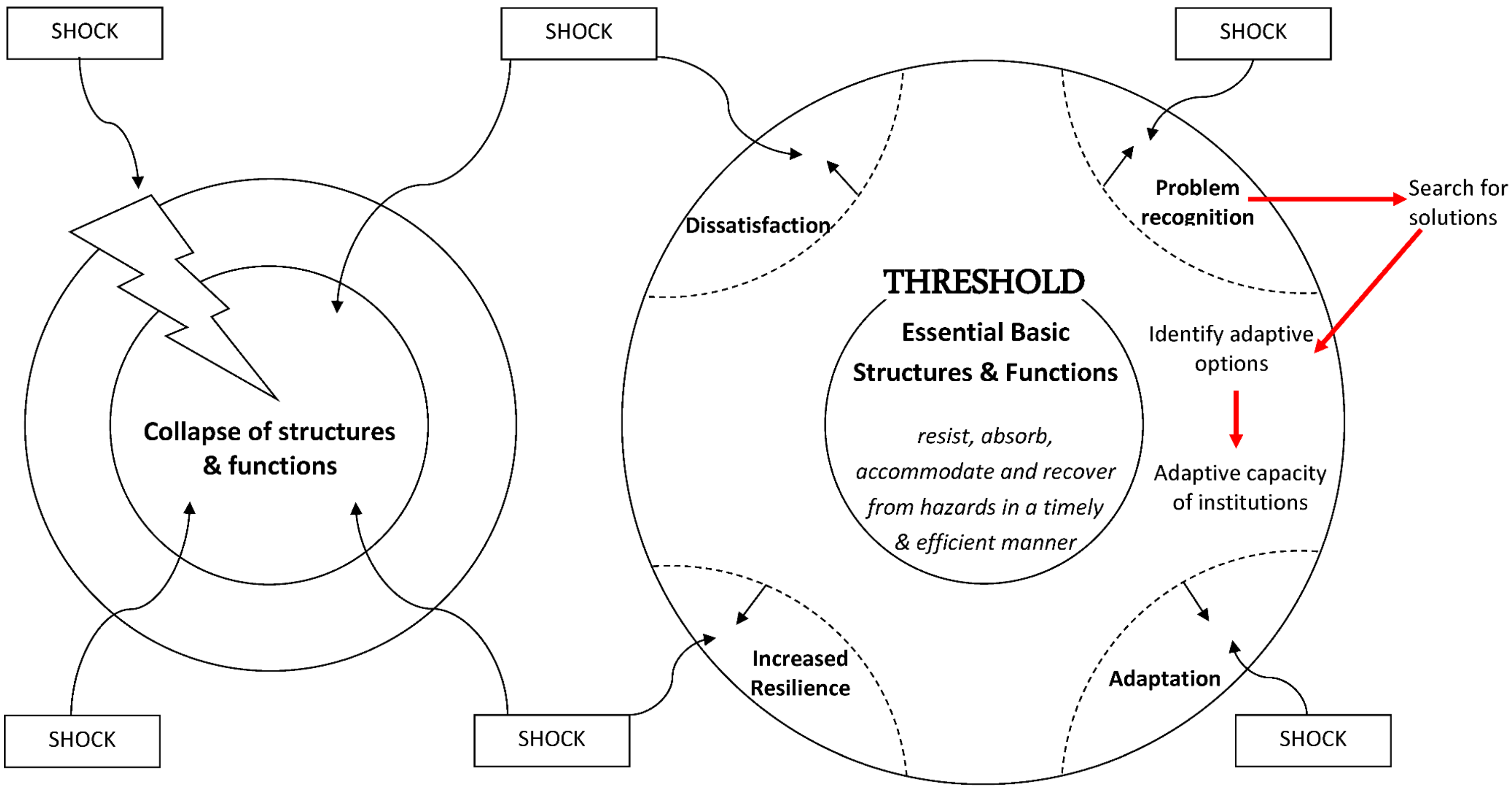

Figure 1.2: The effect of shock on systems that have insufficient (Figure 1.2*a*: left) and sufficient (Figure 1.2*b*: right) resilience.

Where there is high resilience, there should be capacity to foresee problems and adapt voluntarily in a way that causes least disruption to existing structures and functions. Adaptation is therefore more likely to be planned. However, because the aim is minimal disruption, adaptation in the high resilience model is likely to be incremental (due to inertia), which ultimately may not be sufficient (Handmer and Dovers 1996).

A *threshold* surrounds the core. This is a key concept used in resilience theories. If a stress penetrates the threshold it causes system collapse (Walker and Meyers 2004; Renaud *et al.* 2010), though many have noted that the point at which a threshold will be breached in a social system is highly uncertain (Biggs and Rogers 2003). This is depicted in the low resilience model at Figure 1.2*a*.

While the diagrams depict a bounded system, boundaries are in fact porous. Systems are nested institutionally and spatially and are affected and by what happens at higher or lower scales. The increased resilience of one system (or system component) can result in trade-offs that adversely affect another (Walker and Salt 2006; Chelleri *et al.* 2015).

The layer between the outer circle (the system boundary) and the threshold is the resilience layer which acts like a buffer. Whether or not the shock penetrates to the core depends on both the size of the shock and the thickness of the resilience layer. The buffer thickness is influenced by the presence of adaptation barriers and adaptation enablers (social, institutional and physical capital). Barriers and enablers will be present in both high and low resilient systems. However, taking 'information' as an example, there may be lower quality and less accessibility of information where there is low resilience.

The thickness of the resilience layer is also affected by the type, size and frequency of shock. These factors interact and previous shocks (or their absence) may increase or reduce different types of barrier/capital.

The 'low resilience' model (Figure 1.1*a*) depicts the four categories of adaptation barrier: cognitive, institutional, political and resources distilled from the literature review (section 1.5). Adaptation barriers prevent the implementation of effective flood management, resulting in a narrow resilience layer.

The corresponding 'high resilience' model (Figure 1.1*b*) is based on McAslan's resilience framework and shows enabling factors needed to build resilience and effective PPRR strategies (McAslan 2010). McAslan's social, physical and procedural enablers have been modified (as outlined below) and have been inserted into the high resilience layer as 'capital'. Together, the enabling factors influence the capacity to (foresee), prevent, prepare, respond and recover from shocks. Foresight was added to the standard PPRR framework to address criticisms noted in section 1.2. Foresight encompasses activities such as climate research, hazard and vulnerability information, assessment and understanding.

McAslan's original 'procedural enablers' category was extended to more broadly encompass formal institutional arrangements and is shown as 'institutional capital'. 'Physical' capital has been retained as a category but inclusions have been broadened and generalised. Specifics such as 'secure homes'; 'effective warning systems'; and 'means to escape' have been amended to: 'exposure to threat'; 'built environment'; 'natural environment'; and 'technology'. McAslan's original framework includes elements such as encouraging innovation, understanding and evaluating threats and information and knowledge sharing. These are important characteristics of adaptive institutions and have been depicted as 'adaptive capacity', 'information' and 'cross-sector integration and knowledge sharing'.

Where a system has sufficient resilience, shock causes a temporary impact but its resilient properties enable it to 'bounce back' and recover quickly. However, the shock is not without repercussions. Borrowing from comparative public policy, this may result in dissatisfaction, problem recognition, and the search for solutions outside of the system. If institutions have sufficient adaptive capacity, this leads to adaptation, and enhanced resilience (as shown in the 'high resilience model, Figure 1.2*b*). A truly resilient system should have the capacity to distinguish between adaptive and maladaptive solutions and to implement the former. This supports ideas that resilience should have the ability to move beyond pre-existing conditions (Handmer and Dovers 1996; Klein *et al.* 2003; Manyena *et al.* 2011).

Where there is insufficient resilience (Figure 1.2*a*), abrupt and prolonged collapse of structures and functions force transformation of the system, society or community to a new state (structure / function). Changes are reactive rather than planned, are likely to be disruptive and may or may not be adaptive.

6. Methodology

Research questions were addressed by investigating Australian flood management and comparing it with approaches used overseas. The primary method was literature review. Sources included flood reviews, government documents and academic literature, each contributing different perspectives. Flood reviews, typically conducted following large-scale flood disasters, signal system failures and constitute an attempt to identify problems and address them. They mark key moments in time when a society questions the effectiveness of its approach and may embark on a new trajectory. This correlates well with 'dissatisfaction' in comparative public policy methodology (Rose 2005). The second category, government documents, comprised policies, guidelines, legislation, program documents (such as funding agreements, grant criteria and financial statements), technical studies commissioned to assist decision making and media releases. These documents provided the means to analyse motivations and incentives. They also helped to distinguish policy rhetoric from what was actually funded. The last source category, academic literature, enabled a broader perspective on issues, theories and findings of other researchers.

Experience of past inquiries suggests that problem framing may restrict inquiries and their findings (Handmer and Dovers 2007). In-depth, semi-structured interviews (Minichiello 1995) were therefore used to validate and enhance findings of post-2010-11 Australian flood reviews and to gain greater understanding of issues relevant to flood-related climate change adaptation. Nineteen flood professionals were interviewed, with a range of expertise including insurance, local government, emergency management, floodplain management, water utilities and ecosystems research. Suitable interviewees were identified in consultation with supervisors and industry contacts. Research was approved by the ANU's Human Ethics Committee (see Appendix 2 for interview topic guide).

For comparative policy analysis, flood management policies of three other flood-prone countries were investigated (China, the Netherlands and the USA). These were used to develop comparative case studies. Each of these countries has a history of flooding and had recently experienced major flood events, leading to re-assessment of policies and approaches. This enabled the comparison of Australian review findings with those of similar processes overseas. Similarities and differences in approaches to flood management could be identified, as well as causal factors and problem recognition.

These countries were deemed suitable for comparative research for other reasons as well. In the case of the USA, there is evidence that policy transfer to Australia has taken place in the past and similar federation styles of government could have facilitated this. As discussed in section 1.2, modern non-structural approaches were pioneered in the USA and are now used internationally. Furthermore, many flood management frameworks and tools used in Australia, such as PPRR and the standard development planning tool based on a 1 in 100 AEP flood, derive from the USA.

However, a search for solutions confined to the USA would be of limited benefit. Like Australia, the USA has been unable to keep in check escalating damage costs, and historically, America's experience of managing floods does not extend much beyond Australia's. By contrast, China and the Netherlands have some of the longest experience of large-scale flood management. In both countries, flood events and responses have been recorded for centuries. China started building dykes in the Yangtze floodplain in the Eastern Jin dynasty (317-420), while the Dutch built their first comprehensive dyke systems in the thirteenth century (Tol and Langen 2000; Zhang 2006). Such extensive experience meant that these countries offered opportunities for lesson learning, while policy innovations following recent floods enabled investigation of alternative management options.

Approaches to flood management were identified for each country. Adaptive potential of different strategies was assessed using Hallegatte's adaptive characteristics, including flexibility, cross-sectoral synergies and conflicts, reversibility, low cost and 'no regrets' (Hallegatte 2009). Barnett and O'Neill's (2010) characterisation of maladaptation was used to identify least adaptive approaches.

For the resilience component of the work, research was extended to cover global organisations including UNISDR because of their influence in promoting resilience.

7. Thesis by Compilation: Structure

This thesis comprises seven inter-related publications. Figure 1.3, shows how papers integrate and respond to research questions.

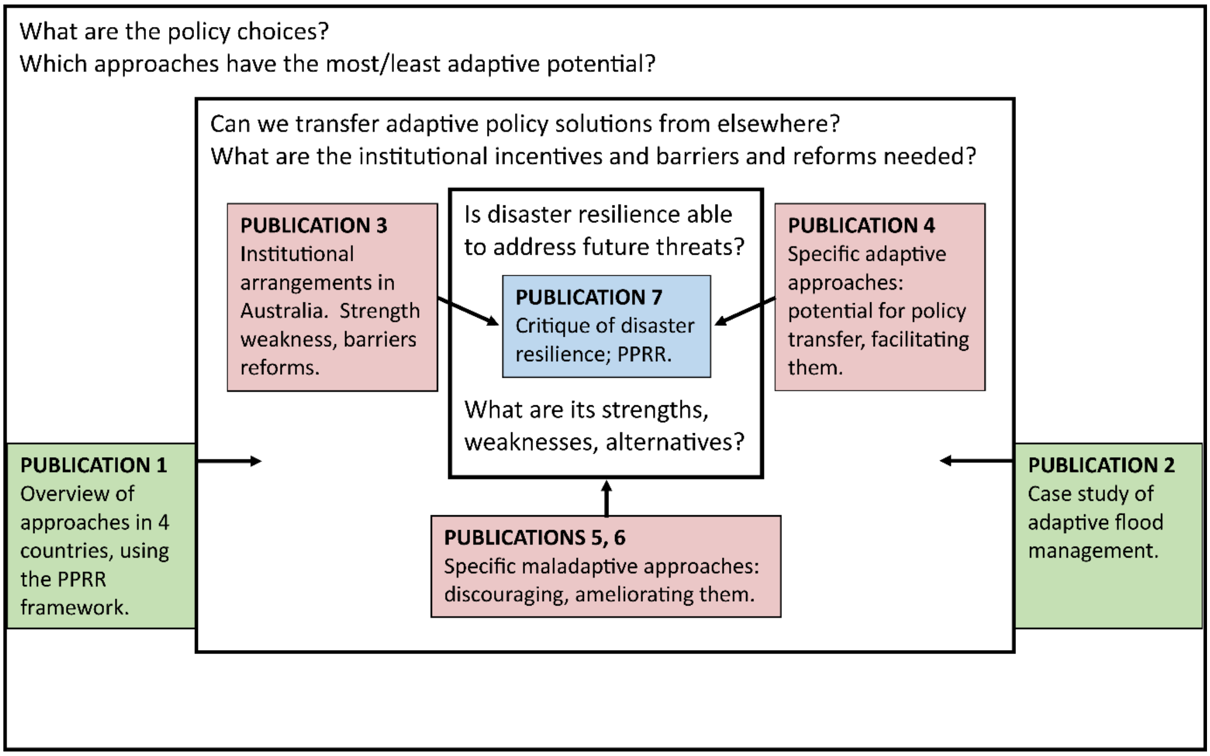

Figure 1.3: Thesis structure and integration of publications.

A. Identifying adaptive approaches

Publication 1: Initial work examines flood management across all stages of PPRR in Australia and overseas. The aim of this work was to identify approaches and measures with the most and the least adaptive potential. The publication summarises these findings and forms a foundation stone for subsequent work. Additional information is at Appendix 4.

Publication 2: Initial work suggested that ecosystems based approaches to flooding have great adaptive potential. However, they appear little understood in Australia. Publication 2 provides a case study of recent 'Room for the River' policy innovations in the Netherlands to enable better understanding of this approach, its origin and implementation.

B. Are adaptive approaches transferrable to Australia? What are the barriers?

Publication 3: This paper focuses on institutional arrangements for flooding in Australia. It draws on post 2011 Australian flood reviews, government policy and funding documents to establish the strengths and weaknesses in Australian arrangements for flood. The focus of the paper is on barriers and reforms for effective flood management. Preliminary investigations were also carried out into the relationship between PPRR and resilience and the way in which these two concepts are used in Australian policy and funding mechanisms.

Publication 4: Publications 4, 5 and 6 take a more detailed look at measures assessed in earlier work as having most and least adaptive potential. Publication 4 focuses on adaptive measures used elsewhere, in particular development relocation (changing land use) as this is often required to implement ecosystem based measures. Current trends in the funding of adaptive approaches in Australia are studied and are found to be declining. The paper examines why relocation is considered feasible in other countries, but little used in Australia. It examines the potential for policy transfer and its challenges.

Publication 5: Levees and similar structural measures generally appear to be maladaptive when assessed against adaptive and maladaptive characteristics. Interestingly, Australia appears to be investing in new levee projects at a time when many other countries that have traditionally relied upon dykes and levees are recognizing problems with this approach. This paper investigates why levees are often viewed as the 'preferred' option. How do governance structures, flood management funding programs, decision making processes and tools influence which measures are selected. In particular, this paper compares decision making processes in Australia with the Netherlands, a place which, as indicated in the publication 2 case study, is attempting to reduce its reliance on structural mitigation. Options to discourage or ameliorate the use of levees are also investigated.

Publication 6: While publication 5 looks at levees in an international context, publication 6 takes a deeper look at levee use in Australia. Aspects investigated include past levee performance and reliability; the relationship between levees and development controls; the implications of climate change; and recent levee-related legislative and administrative changes in the wake of Australia's 2010-11 floods.

C. Do disaster resilience policies support long-term adaptive outcomes?

Publication 7: Research culminates in a final paper that investigates whether disaster resilience provides the policy foundation needed to ensure implementation of the most adaptive approaches and on-the-ground activities. This concept is currently central to disaster management policy globally but it is unclear whether it has resulted in actual policy change or whether it will be adequate to meet the challenges of future flood scenarios. This paper critiques the policy implementation resilience theories, looking at how they are interpreted in four countries and by global organisations. A central question is whether 'resilience' should be retained, abandoned and replaced or modified. The paper also suggests future directions for disaster management.

Publication 1 preamble

Wenger, C, Hussey, K, Pittock, J, 2013, 'Living with floods: key lessons from four Australian flood reviews and similar reviews from the Netherlands, China and the USA', 53rd Floodplain Management Association Conference, Tweed Heads, 28 - 31 May 2013.

Publication 1 is a peer-reviewed conference paper that was prepared for the Floodplain Management Association's annual conference in 2013. It was subsequently published on their website. The paper provides an overview of climate change threats to flooding and flood management approaches based on an analysis of recent flood reviews and reports from four countries. This analysis formed the basis of comparative case studies used in the rest of the thesis (**publication 2** offers a detailed case study of one of these countries). Flood management approaches (structural, non-structural and ecosystem based) were assessed to determine their adaptive potential, given the expectation of more intense precipitation events, changing frequencies and a lower degree of certainty about flood risk due to climate change. The PPRR Framework was used to structure findings. It forms a useful 'before – during – after' categorisation of measures to help assess effective intervention stages. Another advantage of the framework is that it is widely used and understood by emergency managers, and therefore helpful for research dissemination.

Section 1.2 of the paper refers to Appendix 3 of Wenger *et al.* (forthcoming), which has since been published (Wenger *et al*., 2013)[3]. This is found in **Appendix 4** of the thesis. The appendix tabulates individual measures according to the PPRR Framework, assesses their benefits and disadvantages and how they are likely to perform in a changing climate.

Publication 1 key research findings were explored in subsequent work:

Firstly, flood reviews from all countries, including Australia, raised issues with structural approaches, like levees. This was explored further in **publication 5** (in the international context) and **publication 6** (in the Australian context). **Publication 7** investigates the circumstances under which such measures may be used adaptively.

Secondly, **publication 1** findings suggest that better development planning and ecosystem-based measures are highly adaptive for dealing with climate change. Prevention is also more cost-effective than response and recovery in terms of avoided damages. Yet flood reviews and interviews indicate that Australia performs badly at both these activities. Prevention/mitigation, and preventative recovery therefore became a key focus of later publications.

[3] Publication 2 is an extract of the same report.

Living with floods: key lessons from four Australian flood reviews and similar reviews from The Netherlands, China and the USA

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Abstract

2010-2011 saw some of the biggest flood events in Australia's history. The large scale of events prompted numerous inquiries and review processes by different governments and organizations. As climate change is expected to increase the severity and likelihood of flooding events in the future, a project was developed to analyse these reviews and determine if they offered any lessons for climate change adaptation. The project focused on four recent reviews from Queensland and Victoria. The project also compared Australia's review processes and findings with similar processes from the Netherlands, China and the USA to determine points of similarity that reinforced Australian findings and to explore differences.

This paper presents some of the major findings of the reviews. We explore the surprising failure of Australian flood inquiries to address future flood risks from climate change. Conclusions are also drawn as to where Australia is innovating in flood management future and where reforms are needed. Our findings suggest there is potential for Australia to explore ecosystem approaches to flood control, and that reform is needed of land use planning and disaster relief funding. We also look at the adaptive potential of structural and non-structural measures and the role of flood insurance and relocation.

1. Introduction and methodology

2010-2011 saw some of the biggest flood events in Australia's history, with approximately 80% of Queensland declared a disaster zone and extensive flooding in other eastern states, notably Victoria. The scale of events, the number of lives lost and the damage incurred prompted numerous inquiries and review processes by different governments and organizations. As climate change is expected to increase the severity and likelihood of flooding events in the future, a project funded by the National Climate Change Adaptation Research Facility was developed to analyse reviews and determine if they offered any lessons for climate change adaptation (Wenger *et al*. forthcoming). This paper summarises findings from that project.

Four Australian flood reviews were analysed in depth for the project:

- Brisbane City Council's Flood Response Review Board report, or 'Brisbane

Review' (Arnison *et al*. 2011);

- Queensland Floods Commission of Inquiry, or 'QFCI' (QFCI 2012; QFCI 2011);
- Victorian Review of the 2010-11 Flood Warnings and Response, or 'Comrie Review' (Comrie 2011); and
- Parliament of Victoria's Environment and Natural Resources Committee Inquiry into Flood Mitigation Infrastructure in Victoria, or 'ENRC Inquiry' (Parliament of Victoria 2012).

Review processes and findings were compared with similar processes overseas, including the Netherlands, China and the USA to determine points of similarity that reinforced Australian findings and to explore differences. A series of semi-structured, in-depth interviews was also conducted with professionals from relevant sectors including insurance, emergency services, floodplain managers, ecosystem researchers, local government and urban utilities. Interviews were used to validate the research and to obtain a deeper understanding of issues relevant to climate change and adaptation to flooding. An end users committee guided research and identified project communication needs.

The project categorized activities using the standard emergency management framework Prevention-Preparation-Response-Recovery (PPRR) to facilitate communication of the results. As the framework represents a sequential or cyclical timeframe, this also enabled assessment of the effectiveness of different phases of intervention. Consideration was also given to the relative merits of structural and non-structural approaches and to adaptive characteristics such as cost effectiveness, 'no regrets' and multiple benefits.

1.1 Impacts of climate change on flooding in eastern Australia

Anthropogenic climate change is expected to exacerbate natural extremes of flood and drought. Flood patterns are likely to change and it is no longer sufficient to rely on historical data to predict floods:

> Due to changing climate, the frequency and magnitude of floods in the near future is expected to vary across Australia. It has been established that changing climate will have notable impacts on the rainfall runoff process and thus hydrologic time series (e.g., flood data) can no longer be assumed to be stationary. It has serious implications in regional flood estimation, as these are based on past data, which can no longer be taken to represent the future under a changing climate regime. A failure to take climate change into account can undermine the usefulness of the concept of return period, and can lead to underestimation / overestimation of design flood estimates, which in turn will have important implications on the design and operation of water infrastructure.
>
> (Rahman *et al*. 2010: 2)

1.1.1 Rainfall

A rise in the global mean temperature of between 1.4 and 5.8^{0}C above 1990 levels is expected by 2100. This will change flood patterns due to changes in precipitation and sea level rise. There is expected to be increased precipitation intensity, as higher sea surface temperatures result in greater evaporation and warm air can hold more water vapour. Changing circulation patterns will affect rainfall distribution (Meehl *et al*. 2007).

The 2007 IPCC report indicates that while rainfall intensity will increase, rainfall over eastern Australia is likely to decrease overall. Modelling also indicates seasonal changes, with rainfall increasing in summer but decreasing in winter, particularly in the south (Christensen *et al*. 2007). The 'State of the Climate 2012' report anticipates increased spring and summer monsoonal rainfall across the north with a 66% probability of fewer cyclones but an increased proportion of intense cyclones (CSIRO and BoM 2012).

1.1.2 Sea level rise

Sea level rise (SLR) is among the best known effects of climate change. Australian sea levels are increasing but at different rates. The central east and southern coasts of Australia are rising at a rate of around 3mm per year, similar to the global average, whereas the north and northwest of Australia have been rising 7-11mm per year. At this point the rises are primarily linked to warming of ocean waters causing them to increase in volume (CSIRO and BoM 2012).

In recent years projections have been regularly revised upwards as information improves, which suggests risk assessments will also require regular revision and responses will need to be flexible. Projections presented at international fora in 2009 ranged from 0.75 to 1.9m by 2100, with 1.1m being the new mid-range (Australian Government 2009). SLR of 1.1m could expose $226 billion of Australian coastal assets to flood damage and erosion (Australian Government 2011*a*).

1.1.3 Other factors

Changing precipitation patterns and sea level rise are not the only factors influencing flooding. Others include storm surge, land subsidence, soil movements (due to increased erosion), population increase, urbanisation (associated with impermeable surfaces that increases water run-off), landscape modifications (e.g., levees), vegetation cover and soil moisture level. Many of these are exacerbated by climate change.

Vegetation cover in Australia is likely to become sparser with climate change, due to more prolonged droughts (Pittock 2003). Sparser vegetation impairs the ability of the landscape diffuse raindrop intensity, to slow run-off and absorb moisture. According to Nott, such landscapes are more likely to have high run-off and more destructive flash flooding (Nott 2006).

1.2 Adaptation approaches and uncertainty

Much of the uncertainty in climate change science can be attributed to difficulties in determining how much observable change is due to natural variation that occurs over multi-decadal scales and how much is due to anthropogenic causes. In some places, it will be another forty years before changes in precipitation patterns become statistically detectable and distinguishable from natural variation. Hallegatte (2009) suggests and that it is a mistake to wait so long for modelling to be fully validated as by that time maladaptive decisions may have been made. Moreover, projection ranges continue to be large despite improved information, and no matter how advanced the modelling becomes it is unlikely to yield the degree of certainty that planners require. Decision making frameworks need to accommodate this uncertainty rather than delaying action until certainty improves.

Hallegatte presents a number of adaptation characteristics that are less dependent on information certainty, including no-regrets strategies that are beneficial even in the absence of climate change; reversibility; ease of incorporating low-cost safety margins; soft strategies (which by their nature are generally reversible); avoiding long term commitment (uncertainties increase further into the future); and synergies, which consider externalities to other sectors (Hallegatte 2009). Adaptive characteristics such as these were considered when analysing measures proposed to address flood risks by Australian flood reviews and overseas. For more detail please refer to Appendix 3 of Wenger *et al*. (forthcoming).

2. Key findings

2.1 Review processes and treatment of climate change

One of the most notable findings was that Australian reviews virtually ignored the issue of climate change and its impact on flooding. The ENRC Inquiry was the only one of the four reviews to make a definitive statement about anticipated effects of climate change on flooding when setting the context for the review, but even it did not assess the suitability of the measures it proposed to address future threats.

The general failure to address future flood threats constitutes a missed opportunity. It can be attributed primarily to the terms of reference of the reviews which were concerned with assessing performance during the recent flood event and on managing events of similar scale. None of the terms of reference made any mention of climate change or other future conditions that might affect flooding, nor did they offer the flexibility for reviewers to address aspects not covered by the ToRs. This contrasts markedly with overseas reviews, where concerns that climate change will significantly worsen future flooding are often a driving force behind review processes, for example, the Dutch Deltacommissie review (Deltacommissie 2008).

2.2 Australian review findings

Australian reviews varied greatly in their scope. The QFCI and the Brisbane Review covered all PPRR phases. The Comrie Review was very much focused on response, though preparation and immediate recovery were also covered. The ENRC Inquiry looked at selected aspects of prevention, largely constrained by its terms of reference to consideration of infrastructure and waterways maintenance activities such as vegetation clearance.

The reviews overwhelmingly point to the need for improvements in non-structural measures, such as development planning, production and availability of quality flood management information, emergency response management and community participation.

When land is developed it is rarely reversible, and then only at great cost and inconvenience. Development restrictions and building codes are thus a high priority for adaptive management. They depend on information, policy, legislation, tools and processes. The QFCI reveals considerable deficiencies in Queensland's development planning systems at the time of the 2010-11 floods. Development issues were only touched on by the Comrie Review but several points echo QFCI findings, suggesting that issues may not be unique to any one state. Issues relating to development legislation include:

- **provisions that are non-mandatory**, for example, the inclusion of the Queensland Planning Provisions' standard flood hazard overlay in planning schemes was not mandatory.
- **mandatory provisions have conditional application**, for instance, in Queensland SPP1/03 relating to flood risk only applies if planning schemes adopt both a defined flood event and have a flood map; Victorian Planning Provisions only apply if flood mapping has been carried out.
- **mandatory provisions are subject to exemptions**, for example, 'material change of use that is code assessable' is not subject to SPP1/03. Community infrastructure not listed in SPP1/03, including childcare and aged care facilities is exempt, as is development that has 'overriding public interest'.
- **satellite planning schemes** operate under different legislation to facilitate development with specific aims such as affordable housing, essential services, specified localities and significant projects. These provide inadequate or non-existent consideration of flood risk.
- **inadequate building codes**: at the time of the floods, there was no national

standard for construction in flood prone areas; the Queensland Development Code did not cover construction in flood prone areas; Queensland's Plumbing and Wastewater Code did not cover flood resilience; Victoria's Building Act 1993 only regulated floor height and did not cover other design features or flood resilient materials.

Inconsistent development legislation results in ad hoc consideration of flood risk and is likely to reflect conflicting policy objectives, such as immediate requirements for affordable housing versus long term costs in terms of safety and disaster relief. There is a fundamental disconnect in that the majority of relief and recovery funding is supplied by the Federal Government, whereas development decisions are made by state and local governments. Many legislative exemptions appear to increase the vulnerability of disadvantaged groups and compromise the resilience of essential infrastructure. This is an area where major reform is needed.

Building codes can enable people to live in areas subject to less severe flooding and studies suggest that incorporating flood compatibility into the original design is more economical than retrofitting (Jones *et al*. 2006). Flood reviews suggest building codes at both the national and state level are inadequate, though state building codes are expected to be revised to comply with new national standards for residential property in flood prone areas (ABCB 2012*b*).

Reviews also revealed inadequacies in the administration of planning processes. In one example, lack of accountability by state government agencies responsible for assessing and approving local planning schemes resulted in non-compliant planning schemes for places such as Brisbane and Emerald. Issues included failure to adopt a defined flood event (DFE) and inadequate flood mapping (QFCI 2012).

Adoption of a DFE is a key planning tool in both Queensland and Victoria. Queensland's state planning instrument for flood risk, SPP1/03, cannot be applied unless planning schemes adopt a DFE. The DFE is based on an historic flood and generally a 1:100 year event is selected, with an additional freeboard of 300-500 millimetres (Comrie 2011; QFCI 2012). Recent studies suggest that the use of the 1:100 year event standard for flood control may be inadequate, particularly in countries with a short term flood records like Australia (Wenger *et al*. 2012). As flood frequency is calculated on past flood events, any subsequent severe flood adds to data and can lead to recalculations. Inaccuracies can also occur as a result of out of date techniques and assumptions. Whether due to inaccurate data, climate change or urbanisation, the 1:100 flood line is not static but can move. This can place people at unacceptable risk of flooding.

There are significant barriers to incorporating up-dated information into planning schemes in both Victoria and Queensland, including a ten-year interval before some planning instruments become due for revision, complex approval processes, cost, compensation liabilities and competing policy pressures. These can all prevent timely incorporation of flood data into planning schemes (Wenger *et al*. 2012). Climate change risks are not consistently managed in land-use planning schemes, with local governments hampered by a lack of guidance from state governments and financial and expertise constraints (Productivity Commission 2012). Projects such as Queensland's Inland Flood Study and Engineers Australia's Australian Rainfall and Runoff Revision Project could improve incorporation of climate change risks into future flood studies.

Accurate flood information is a prerequisite for the application of planning legislation and instruments that address flood. It also enables risk assessment and implementation of mitigation measures. However, it has proved challenging to gather and incorporate flood information into planning schemes in most municipalities, even without factoring in the added threats of climate change.

Analysis of reviews revealed gross inadequacies in the generation and dissemination of flood information. In Victoria, 80% of floodplains were reportedly mapped for a 1:100 year event but only 70% of these mapped areas were incorporated into planning schemes. In Queensland, most towns and cities are built on floodplains but only 37% of planning schemes contained any flood related mapping. Of these, only 23.6% were completed in accordance with the SPP 1/03 Guideline (Comrie 2011; QFCI 2012).

Reviews do not consider future flood risks when assessing the relative merits of different types of flood information. For example, when discussing likelihood mapping, the QFCI does not acknowledge that stationarity is likely to cease with climate change and that historical likelihood will no longer be accurate (QFCI 2012). This is a notable omission that suggests a lack of comprehension about how climate change is expected to influence future flooding.

The collection and use of locally based flood information is hampered by insufficient local government resources (both technical and financial) to fund flood studies and to defend and compensate development decisions that are made as a result of using that information. Other issues include municipal boundaries that inhibit the production of catchment-scale flood studies, community cost in terms of lower land values and higher insurance costs and difficulties in downscaling climate change information. Such barriers need to be overcome to facilitate production, availability and use of flood information. The Queensland Reconstruction Authority's (QRA) maps were produced cheaply, covering floodplains over the entire State. They provide a positive example of how some of these difficulties can be overcome.

All reviews were cautious about recommending structural measures such as use of levees and other engineering methods. Where levees were viewed as appropriate it was mainly in terms of protecting existing urban development or individual assets. Significant failings were found in levee regulation, particularly in Queensland where levees are sometimes completely unregulated. Victoria's ENRC Inquiry made many administrative and legal recommendations, suggesting that strong regulation is required where levees are used, and that failure to do so can result in heightened flood risk (Parliament of Victoria 2012; QFCI 2012). These findings were strongly supported by the US case study.

Dams were generally found to have mitigated the effects of flooding (including in the case of Wivenhoe Dam). The likelihood that dams might have encouraged the development of flood prone land below them, thereby increasing the consequences of flooding, was not discussed by the Inquiry, despite the interim QFCI reporting 'a popular misconception that Wivenhoe Dam would contain all floods emanating in the upper Brisbane River' (QFCI 2011).

The conflict between water supply and flood mitigation is likely to be exacerbated with climate change as more severe droughts as well as floods are anticipated. This conflict is clearly demonstrated by the QFCI, with administrative deficiencies blocking the temporary alteration of the full supply level of Wivenhoe dam to accommodate forecast floods.

The QFCI raised a number of issues about dam safety that could be cause for concern if they are to cope with increased amounts of water in the future due to climate change. Separate studies into dam safety indicate compliance with ANCOLD standards by private dam owners is poor, with high dam failure rates posing threats to downstream communities (Pisaniello 2010). Pisaniello's study coupled with the findings of the QFCI suggest an Australia-wide review of dam safety might be advisable, including assessment of future threats such as population movements and increased inflows due to climate change.

Only the ENRC Inquiry looked at the management of natural assets on a landscape scale as a method to address flood impacts and this was limited to the management of riparian vegetation and debris. The QFCI touched on vegetation management but yielded no recommendation. The ENRC Inquiry found that in most cases vegetation clearance had a negligible effect on flood depth, while vegetation growing in and around rivers had significant flood reduction benefits. Vegetated waterways were found to delay peak discharge and reduce both flood depth and velocity on a catchment scale. This challenges popular perceptions and practices of removing vegetation from watercourses.

Most Australian flood studies and management measures are carried out on a local level. However, catchment scale management is needed to manage of flood risks, and mitigation measures such as levees, vegetation management and development planning. In Victoria, the development approval process provides a catchment perspective through the official involvement of Catchment Management Authorities as designated referral agencies. These powers are currently under threat (Parliament of Victoria 2012).

Community resilience and shared responsibility are currently receiving much attention, and if climate change is expected to deliver large scale flood events in the future, helping people to become more self-reliant will be a benefit if emergency services are overwhelmed. There was strong support in all reviews for public availability of flood risk information to help achieve these outcomes. Recommendations relate to methods of communicating flood risk, and improved forecasting and warning. The Comrie Review reported successful outcomes using the FloodSafe program. However, the same report also noted significant difficulties in modifying human behaviour as opposed to more proactive approaches such as development controls. Furthermore, while public awareness of flood risk is important, the capacity of vulnerable groups such as the poor and the aged to avoid or mitigate flood risk is limited.

All reviews reveal issues with flood data collection and the coverage of warning networks. This has relevance to climate change as better coverage can help manage ‘unprecedented’ events and increase warning times for flash flood. The Comrie Review endorsed the use of the Total Flood Warning System as best management practice. Resourcing was found to be the biggest impediment to improved data collection.

Emergency management agencies were found to suffer significant governance, capability and capacity issues. Reviews found inadequate resourcing of local governments and response agencies, lack of clarity regarding roles and responsibilities and inadequate oversight and accountability. Reviews also highlighted a need for improved evacuation planning by local authorities (Arnison *et al*. 2011; Comrie 2011; QFCI 2011).

While an ‘all hazards, all agencies’ approach was recognized as the ideal, this was far from being realized in practice. Improved interoperability of both agencies and technology were needed and in Victoria, trigger mechanisms to enable scale-up of operations.

In terms of immediate recovery, administrative processes such as processing individuals requiring assistance; volunteer management and complexity of recovery grants and reimbursement processes were identified.

Of the four reviews studied most closely, the QFCI dealt with insurance issues in greatest detail, and they were also the subject of industry specific reviews. Assessment processes to handle bulk claims were generally found to be appropriate and the majority of claims were determined in the 1-2 month period. More problematic were the availability and affordability of flood insurance and the need for greater availability of flood risk information. Particular issues were identified for low income earners who are susceptible to being uninsured or underinsured (QFCI 2011; Trowbridge *et al*. 2011).

Betterment, or rebuilding to more resilient standards, was covered in most detail by the Comrie Review. While technically allowed by the Natural Disaster Relief and Recovery Arrangements, at the time of writing, no betterment project had ever been approved (Comrie 2011). This exposes Australia to repeat damage costs. The most significant impediment to achieving betterment is the need for damaged infrastructure to be rebuilt as soon as possible. However betterment projects, requiring both an application and cost benefit analysis, take time to prepare and approve. Agreed processes to identify and pre-approve infrastructure eligible for betterment could improve future resilience.

The COAG National Strategy for Disaster Resilience lists as a priority outcome:

> Following a disaster, the appropriateness of rebuilding in the same location, or rebuilding to a more resilient standard to reduce future risks, is adequately considered by authorities and individuals
>
> COAG 2011: 12)

There were isolated examples of relocation following the 2010-11 floods at Grantham, QLD and in the Lower Loddon, VIC, but relocation is not a consistent policy and the lack of functional betterment provisions makes it clear that COAG's aspirational objective is far from being realised.

2.3 Overseas findings

In contrast to Australian reviews, overseas reports overwhelmingly point to a need for ecosystem approaches to flood control. The Netherlands and China rely heavily on dyke systems and although they are strengthening key dykes, they are dismantling or allowing 'flow through' of others. In the Netherlands, 'Room for the River' programs put in place measures such as levee setback, land purchase and reversing channel straightening activities to give more room for floodwaters. These programs have a strong focus on integrating the interests of stakeholders to find optimal solutions, resulting in multi-functional landscapes and minimal conflict (Dutch Government 2006; De Boer and Bressers 2011*a*).

In China, integrated river basin management is a key strategy. Logging bans and revegetation of upper catchments is combined with reversing land reclamation practices that have seen large inland lakes shrink by as much as 80%. The aim of these measures is to reduce significant erosion and sedimentation and to increase the water storage capacity of the landscape (CCICED 2004; P.R.C. 2007; Te Boekhorst *et al*. 2010; Pittock and Xu 2011).

Relocation is a strategy used by all three countries. It can provide flood storage capacity when vacated land is assigned to flood compatible uses such as nature conservation, recreation or flood compatible farming.

In the US, ecosystem approaches are starting to find favour as the limitations and costs associated with structural approaches become more apparent. Numerous US reviews and reports present a convincing case for the view that levees are an expensive measure that should only be used as a last resort (Wenger *et al*. forthcoming).

Ecosystem approaches are actively promoted and the use of levees discouraged by the USA's Federal Emergency Management Agency in floodplain management courses and text books (Freitag *et al*. 2009).

The US reports look in some detail at the role of flood insurance, the adequacy of the 1 in 100 year event standard and government disaster relief and mitigation funding.

Initially voluntary, participation in the National Flood Insurance Program (NFIP) became pseudo-mandatory when the Federal Government introduced the Flood Disaster Protection Act in 1973. This prohibited federal agencies from providing communities with assistance in floodplain acquisition or construction unless they participated in the program. As in Australia, land use planning is the responsibility of state and local government in the USA. However, the NFIP has enabled federal involvement in development control through the provision of incentives. Those who voluntarily participate are subject to mandatory provisions, and in return receive flood insurance (Wright 2000). While federal flood insurance is unlikely to be a suitable solution for Australia, some NFIP initiatives, such as the provision of supplementary insurance to enable people to rebuild or repair to improved standards, could be adopted by insurers as an optional product to help people mitigate against future damages.

Widely used in Australia as a *de facto* standard for flood management, the 1:100 year flood event was first selected for this purpose in the USA. It originated as a purely arbitrary actuarial standard to implement the NFIP and was never intended to be a safety standard. The numerous reports and review processes studied for this project point to its inadequacy, with many recommending use of the 1:500 year event, particularly for urban areas where the consequences of flooding are greater and evacuation more difficult. The Netherlands, unlike the US, takes a highly conservative approach to planning controls and in some coastal areas the safety standard is as high as the 1:10,000 year event (1:1,250 for riparian areas). With 50% of its land area at risk, the Netherlands cannot afford any mistakes and it manages floods with the consequences of failure in mind.

US reports provide a cautionary tale for the provision of over-generous disaster relief, as this can remove the incentive for communities to put in place adequate preventative measures. The US's federal disaster relief is increasingly merging with mitigation, with 15% of funding being required to be spent on measures such as voluntary land purchase, relocation and house raising. Evidence suggests that this has resulted in billions of dollars of savings in avoided damage costs from subsequent flooding events (Wright 2000; Freitag *et al*. 2009). In view of enormous taxpayer expenditure following Australia's 2010-11 floods and the virtual impossibility of obtaining approval to rebuild to more flood resilient standards through the Natural Disaster Relief and Recovery Arrangements, these findings are highly relevant to Australia, and consideration could be given to allocating a set proportion of disaster recovery funds towards improving the future flood resilience.

2.4 Interviews with Australian experts

Interviews revealed strong support for development controls by the vast majority of participants. Significant issues to be overcome included competing policy priorities; the lack of availability of flood free land; the limitations of development approval processes; flood studies that are done on a local rather than a catchment scale; lack of accountability and consequences for those who make development decisions; and difficulties involved with rezoning land when there are inadequate resources to provide compensation.

Generally interviewees did not favour levees as a solution to flooding on a rural landscape scale but there was support for levees that protect existing built development. Numerous issues were identified by participants, among them cost, externalities, difficulties regulating pseudo-levees, impaired drainage and levee failure due to breaching or flooding from unexpected sources.

In terms of response, flood warnings and flash flooding, evacuation, flood planning and community resilience were key concerns and recommendations relating to these in the reviews were supported.

Another strong finding was the potential for use of ecosystem approaches to flood management, by reducing floodwater velocity (identified by many as causing the greatest damage to assets) and flood depth. Crucially, these approaches also delay flooding, which is of value in increasing warning times. This has significance to climate change scenarios that are likely to bring more intense rainfall and flash flooding.

Unsurprisingly, ecosystem approaches tended to be strongly supported by ecosystem researchers and floodplain managers, though other sectors had less familiarity with these approaches and were more cautious. Positive examples of the cost effectiveness of this approach were provided, with measurable cost benefits for water supply and water quality (QCC

2012; Queensland Government 2012*a*). To enable this approach, a catchment scale approach to planning and implementation is needed and funding mechanisms, such as payment for ecological services schemes would have to be investigated. Incorporation of ecosystem approaches is needed in flood management courses that currently have an engineering focus, and the level of understanding about such measures also needs to be raised among decision makers and the general public.

There was strong criticism of the government's lack of funding for flood mitigation and betterment, and many found disaster relief over-generous and untargeted. It was not felt that disaster relief in its current form would increase Australia's resilience to disaster. This is a significant issue if the government wants to improve Australia's capacity to adapt and lessons could be learnt from America about merging recovery efforts with mitigation.

Interviews with insurance professionals suggest the industry has limited means of factoring climate change projections into policies due to the need to be cost competitive, though one interviewee noted this is more likely to be achieved if local flood studies incorporate climate change scenarios. However, the industry is very vulnerable to losses if it underestimates risks. One option could be to facilitate and provide incentives for policy holders to undertake flood prevention measures.

Following the American example, there may also be potential for the industry to offer new products such as supplementary insurance for improved rebuilds.

3. Conclusion

It is extraordinary that the Australian reviews don't address climate change threats. However they do highlight many opportunities for improving management of flood risks. The majority of recommendations are non-structural, covering aspects such as governance, legislation, administrative processes, communication and resourcing at all stages of PPRR. Improved development planning, emergency planning, flood information and warning systems received particular attention. One positive innovation is the QRA maps that have provided economical baseline flood mapping in Queensland, and consideration could be given to duplicating this exercise across Australia. In terms of Hallegatte's adaptive strategies, these measures are no regrets, soft and reversible and are a high priority.

Structural measures are associated with the greatest number of problems. Such solutions can be appropriate to protect existing assets but they are inflexible, costly and are often associated with negative externalities. Where such measures are used, careful assessment and management are needed, considering contingencies and cumulative impacts across catchments.

This analysis shows that ecosystem approaches are a neglected area in Australian flood management, but are well supported by findings of the ENRC Inquiry. Such measures have the potential to reduce flood peaks and velocity and can benefit existing development. As ecosystem approaches often come with co-benefits, they have great adaptive potential. Implementation requires administrative systems that support a catchment based approach. Other areas requiring more attention include a more systematic approach to voluntary buy back of repetitively flooded properties and processes to incorporate flood resilience into reconstruction.

To improve future resilience to floods in Australia, reform is needed to relief and recovery funding to emphasize betterment, and barriers need to be removed to ensure consistent consideration of flood risk in development planning and legislation.

Publication 2 preamble

Wenger, C, Hussey, K, Pittock, J, 2013, 'Living with floods: Key lessons from Australia and abroad', National Climate Change Adaptation Research Facility, Gold Coast, pp.264. ISBN: 978-1-921609-89-3.

[the extract reproduced in this thesis is Section 6: 'Overseas studies'; Section 6.2: 'The Netherlands']

Flood reviews examined in **Publication 1** indicate that Australia is ill-equipped to deal with large-scale flood events. Such events are arguably likely to become more common as a consequence of climate change and drivers like population growth and movement. However, Australian flood reviews displayed little, if any, appreciation that threats may increase due to climate change (most did not even refer to climate change) and they consequently failed to examine how best to prepare Australia for future threats. In the words of the most recent IPCC AR5 WGII report, Australia's 2010-2011 floods showed that in some places it has 'a significant adaptation deficit' to *current* risk, even without taking climate change into account (IPCC 2014). If Australia's approach is not adaptive, this begs the question: what does an adaptive approach look like?

Publication 2 answers this question by providing a case study of the Netherlands, a country that has been implementing some innovative policy changes since the 1990s when it experienced a series of 'near miss' flood events in 1993, 1995 and 1998. These floods almost overtopped the dyke system and exposed a failure, spanning several decades, to implement maintenance plans in susceptible areas such as the province of Gelderland (Bezuyen *et al.* 1998). The floods revealed the limitations of traditional structural approaches to flood management, particularly in the light of future climate projections and flood scenarios, and prompted new ways of thinking about flooding. While there are many contextual differences between Australia and the Netherlands, the Dutch example shows what can happen over the longer term if there is over-reliance on structural approaches. It also provides ideas about alternatives.

Publication 2 was revised for a small print run in 2015 (this is the version used in the thesis). Other than minor formatting, the most significant change was to the figure for the amount of land below sea level. The incorrect figure originated from the Netherlands Environmental Assessment Agency and was used by the IPCC AR4 WGII report 2007 (IPCC 2007*a*: 547). The mistake was reproduced in many documents, including those of other Dutch Government agencies before the error was noticed (NEAA 2010; UNEP 2010*a*). My update rephrased the percentage in terms of area susceptible to inundation, following van Alphen (2013).

Living with floods: Key lessons from Australia and abroad: Overseas studies: The Netherlands

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1. The resources selected

The primary references for the Netherlands were selected by the research team on the basis of their influence and/or innovation.

A key resource used was Working Together with Water: *A Living Land Builds for Its Future – Findings of the Deltacommissie* (Deltacommissie [Delta Committee] 2008).

The first Deltacomissie was formed following disastrous floods in 1953. That committee introduced risk-based approaches to flood protection and focused on engineering works to address threats. The report of the Deltacomissie 2008 is the second major nationwide review of Netherlands flood defences. The second Deltacomissie was appointed not in response to a past flood event, but specifically to address future flood threats to coastal regions due to climate change. The *terms of reference* of this review are expressed as a broad mandate:

The committee's task is to advise the Secretary of State on:

a. expected sea level rise, the interaction between that rise and the discharge in the major rivers in the Netherlands and such other developments, climatological and societal, until 2100–2200 as are important for the coast of the Netherlands;

b. the consequences of such developments for the Dutch coast;

c. possible strategies for an integral approach leading to sustainable development of the Dutch coast, based on a) and b); and

d. to indicate the additional value to society of such strategies, in addition to the safety of the hinterland, in both the short and long term.

(Deltacomissie 2008: 101)

The terms of reference are expanded upon in a two-page explanatory note that emphasises the driving threat of climate change. It directs the Committee to identify future opportunities as well as threats; to consider temporal and spatial effects of options on the environment; to consider interactions between coast and rivers; and to take an intersectorial approach. There is an emphasis on innovative measures: 'creativity, imagination, and the ability to think outside existing contexts' (pp. 101-104).

The terms of reference are thus very broad and open-ended, leading the Deltacommissie to describe not only its mandate but also how the Committee interpreted it. The Committee described its task as 'how the Netherlands can be made climate proof over the very long term: safe against flooding, while still remaining an attractive place to live, to reside and work, for recreation and investment'. This articulates the mandate in terms of core societal values.

The two key issues identified by the Deltacomissie were water safety (in terms of both flood protection and securing fresh water supplies) and sustainability. The focus of the latter was to identify flexible and cost-effective measures that give additional value to society, and that can be implemented gradually. The sustainability criterion also meant working with rather than against ecological processes and climate change (p. 9).

The Deltacommissie team comprised 10 members (including the secretary, also a water safety expert). The Committee was chaired by Professor CP Veerman, a specialist in sustainable rural development. Also on the committee were experts in the fields of climate science, hydrology, coastal engineering, economy, agriculture, local government, and spatial planning and urban development.

In addition to the Deltacommissie review, the following references and processes were examined:

- *A Different Approach to Water, Water Management Policy in the 21st Century* (Dutch Government 2000) – referred to in this report as the '2000 Water Policy';
- *Spatial Planning Key Decision Room for the River* (Dutch Government 2006) and the complementary Meuse Works program; and
- *Complex and Dynamic Implementation Processes: The Renaturalization of the Dutch Regge River* (de Boer and Bressers 2011*a*) – referred to in this report as the 'Regge Report'.

These reports discuss some significant flood programs and policy approaches being implemented in the Netherlands that were initiated prior to the Deltacommissie 2008 Review, largely in response to a series of floods in the 1990s. They are complementary in that they focus on riverine flooding rather than coastal sea level threats. Two of these, the Room for the River and the Meuse Works programs, were assigned high priority for implementation by the Deltacommissie 2008 review. The third is a river restoration project on the Regge River that was initiated in 1998 and is due to be completed in 2018. The implementation of the project was recently the subject of a detailed study.

2. Similarities to Australian reviews

While there are many flood-related issues in common with Australia, generally there is little similarity in the approaches taken to address them. Some overlap occurs in measures such as amendment of administrative, institutional, legislative and management arrangements as well as adequate resourcing. Response measures such as warning systems and evacuation are important, but tend to be given less emphasis than more preventative measures. Spatial planning is an area that receives much attention and community participation is also seen as extremely important (though primarily in prevention / mitigation).

Similar to Australian reviews, the Deltacommissie and the 2000 Water Policy recognise the need for *defined roles, responsibilities and authority* (Deltacommissie 2008: 77; Dutch Government 2000: 53). The Deltacommissie proposes legislative and administrative arrangements to achieve its recommendations, including a Delta Act, a Delta Programme, and national and regional bodies to ensure implementation. Current audit standards and methodology are found wanting in dyke maintenance programs and revised processes proposed (pp. 47-49). The report recommends a dedicated funding source isolated from normal budgetary processes in the form of a Delta Fund to ensure funding is not a constraint, using gas revenues and government bonds (pp. 77-84). Legislation to quarantine funds ensures partisan politics do not compromise flood security.

The Regge River restoration project report highlights the vulnerability of complex multi-sectorial projects to changes in national policies or regional administrative arrangements. Restrictions on organisational expenditure have recently been introduced, meaning that activities can only be funded if they have direct relevance to their sector. This has resulted in a more *siloed approach* that is not compatible with integrated and multi-functional land-use projects (de Boer and Bressers 2011*a*: 12, 196-197, 201). This is reminiscent of issues with Victoria’s disaster management framework, where a siloed approach was not appropriate for the cross-sectorial nature of the task.

The *pressure for space* has resulted in competition for Dutch land between different sectors for residential, agricultural, industrial and infrastructure uses. The amount of land available for water and nature (excluding forest and woodland) decreased markedly between 1950 and 1990, by 15% and 44% respectively, while agricultural land area decreased by approximately 6% (de Boer and Bressers 2011*a*: 17).

Even though Australia has fewer population pressures than the Netherlands, Australian urban centres experience significant space pressures, resulting in concerns that floodplain land not be ‘sterilised’, or unnecessarily made unavailable for use (NSW Government 2005).

In the Netherlands, there is a similar concern not to prohibit development on flood-prone land. The Deltacommissie, while discouraging development on such land, recognises space scarcity and takes the view that, providing river discharge capacity is not impeded, and providing the ability to increase levels of water storages is retained, floodplain development could take place using innovative building design, amendment of building regulations and structural measures (Deltacommissie 2008: 49, 52, 90). Possible building design measures include houses on floating platforms, houses on stilts, use of waterproof materials (if flooding is shallow but frequent) and the use of artificial mounds in areas with little flow. These artificial dwelling mounds, or 'terps', have been used in the Netherlands as defence against flooding since the Middle Ages. This measure is being reintroduced in some areas that are being depoldered as part of the 'Room for the River' program (reversing land reclamation measures). Relocating businesses and homes to mounds enables people to continue to live in these areas (Dutch Government 2012).

Dutch documents reveal conflict between municipalities that are responsible for development planning and Water Boards, which have an interest in leaving areas at risk of inundation undeveloped. The Dutch government is concerned that too much land has been reclaimed from river systems that now have insufficient space, resulting in higher flood risk. Its 2000 Water Policy requires all new spatial planning to be subject to a water test:

> The 'water test' applies to all manner of spatial planning decisions, including amendments to zoning plans, regional plans, new plans for infrastructure, residential construction, business parks and redevelopment plans in urban and rural areas. The 'water test' allows the consequences for safety and water-related problems to be assessed in relation to the ramifications on water quality and dropping water-tables.
>
> (Dutch Government 2000: 45)

Water and its natural movements are now 'a key determining factor in spatial planning' (de Boer and Bressers 2011*a*: 25; Dutch Government 2000: 43). This is reminiscent of the situation in Victoria, where councils need to refer development approvals in flood prone areas to catchment management authorities – although in the case of Victoria, the government has chosen the opposite approach and is removing assessment powers from catchment authorities (Comrie 2011; Ryan 2012).

While the Dutch government does not prohibit development on flood-prone land (Deltacommissie 2008: 49-52, 90), it is much less willing to subsidise the consequences than the Australian government has been. The Dutch government sees its role in managing floodplain development (outside dyked areas) as '[to] inform, advise, alarm and (if necessary) evacuate and [to] impose building requirements'. The costs of construction and maintenance of protective measures, as well as the costs of flood damage and reconstruction, are to be borne by residents and users who benefit, and not passed on to different administrative levels or society in general (Deltacommissie 2008: 49-52). However, the government is subject to compensation claims resulting from flood damage to areas within dykes where safety levels apply (Dutch Government 2000: 63).

The issue of *insurance* arises in some documents, with a government task force set up to investigate 'the (im)possibility of insurance coverage for weather sensitive sectors'. The taskforce aim was to make flood damage insurable, though it is not clear if affordability was also a concern (Dutch Government 2000: 23). Insurance against flood continues to be unavailable in the Netherlands (Petherick 2011). The Deltacommissie gives a brief but pertinent commentary relevant to insurance and community resilience in its Appendix 4:

> Looking at the organisation of flood protection, one can discern an Anglo- Saxon style, based on a great deal of individual responsibility and the operation of the market, and a Continental style with the government taking responsibility. Lessons from the USA and the UK teach us that leaving responsibility to individuals does not always mean that they accept it … Flood protection often remains confined to local 'postage stamps' based on local cost-benefit considerations and so do not always form a consistent whole … Damage control and disaster management (and insurance) are better organised in countries with poorer levels of protection (and more frequent flooding).
>
> (Deltacommissie 2008: 118)

While this suggests that community resilience is not given as much emphasis in the Netherlands as it is in Australia, *community involvement* is significant in the Dutch approach to land-use changes. It is also worth noting that, in the Netherlands, local communities have significantly more autonomy and power than they do in Australia, which also gives them local responsibility.

The need for community involvement is highlighted in the Deltacommissie Report (2008: 45, 79). The effectiveness of this strategy is demonstrated in the Regge River renaturalisation project. This is a large and complex project aiming to restore the entire length of the river for the dual aims of water storage (buffering capacity in times of flood) and nature conservation. The project was broken up into numerous sub-projects to make it more manageable, working with various communities and municipalities along the length of the river. The project required land to be acquired along the river and/or for its designated use to be changed. A decision was made for the project to employ *voluntary* measures. This was seen as extremely important, as projects in neighbouring areas that used compulsory means to change land use took 20-30 years to complete due to opposition (p. 106). The community consultation strategies were extremely successful in preventing conflict and lengthy litigation processes (pp. 106-107, 126-130, 148, 154, 177-178, 184, 201).

Community involvement strategies are currently being employed on a much larger scale to implement the Wealthy Waal Programme. This programme aims to provide more room for the Waal River to accommodate higher river discharges, while at the same time identifying opportunities for joint benefits for achieving other objectives, such as shipping, economic activity, farming, nature protection, tourism and recreation (de Hartog 2012).

Community involvement was also used successfully in the Room for the River program at Nijmegen to reduce conflict following a controversial decision to relocate a dyke and demolish 50 houses (Dutch Government 2012: 7; Nijssen 2012: 4). This location was particularly vulnerable to flooding, as a narrow bend in the river formed a bottleneck, causing water to back up during a flood. Once a decision had been made by central government, the municipality affected was granted responsibility for developing a plan that would be acceptable to all parties. A similar strategy was successfully used at Diepenheim for the Regge project (de Boer and Bressers 2011*a*: 106-107).

Raising community awareness of flood risk is an issue that receives attention, but more in the context of achieving political support for new water safety measures rather than community resilience (Dutch Government 2000: 21).

Evacuation as a measure to reduce the consequences of climate change is largely left untouched by the Deltacommissie Report, as it is focused on prevention rather than contingency. However, an early warning, crisis management, evacuation plans, routes and locations are listed in the mix of measures that should be used (pp. 41, 119). Other Dutch literature covers response mechanisms in more detail. Evacuation of people and cattle was on a massive scale in the 1995 floods, and 250,000 people and 100,000 cattle needed to be evacuated (Dutch Government 2008: 16). Thus, even if it is not the primary focus, it is a very significant strategy for the Dutch. As in Australia, municipal governments are responsible for developing evacuation plans (Dutch Government 2008: 48). The Dutch use tools such as the 'Standard Method for Calculating Flood Damage and Victims', which maps the number of victims and expected flood damage, to assist the assessment of evacuation needs. Other tools help plan evacuation routes. Work has also been carried out on evacuation decision-making, to determine when to evacuate – for example, Frieser's work on a probabilistic evacuation model rather than a deterministic approach (Frieser 2004). Determining suitable evacuation routes and trigger points has also been an issue in Australia (Opper 2000; QFCI 2011: 188–

192; QFCI 2012: 173–175). Response concerns such as these show little fundamental difference to those expressed in Australian reviews.

3. Different approaches

The approach taken by the Netherlands to flood review and flood management is remarkably different from the Australian approach. While the Australian reviews are very much focused on analysing a past flood event to improve the outcomes of future events (with similar characteristics), documents from the Netherlands are firmly focused on changes to future flood threats.

3.1 The review process

As seen above, the terms of reference of the Netherlands Deltacommissie are quite different from those of the Australian processes, allowing latitude for innovation and specifically asking for measures that can address accentuated flood risk due to climate change causes. They do not call for detailed analysis of a past event, which seems to result in less focus on finding out what went wrong with a specific event's preparation, response and recovery. It is more concerned with broader prevention and mitigation strategies. Interestingly, the Dutch terms of reference specifically call for investigation of opportunities. This is very important in shaping the receptiveness of people who are asked to adapt to climate change threats. If climate change is only seen as a looming threat of massive proportions, it becomes a monster from which people shy away. Transformed into positive opportunities to create more land or to improve its quality, safety and economic advantages, adaptation to climate change becomes much more digestible.

Although the Deltacommissie (2008: 7) explains that its purpose is not so much to respond to a past event but to anticipated future events, this is not the entire story, as the Deltacommissie builds on previous work, such as the 2000 water policy 'A Different Approach to Water' and river restoration programs. These were developed in response to a series of flood events in 1992-93, 1995 and 1998 that caused widespread evacuations and property damage (de Boer and Bressers 2011*a*: 24). The floods could have been much worse than they were, and are described in some documents more in terms of a near miss as dykes were not breached (Dutch Government 2000: 11; Dutch Government 2006: 7; Dutch Government 2012: 5). While the Deltacommissie Report responds to anticipated threats, it was the floods of the 1990s that caused the Dutch to reassess their water policy, and much of the thinking, and even the language of the Deltacommissie, reflects the 2000 Water Policy. The flavour of the Dutch review is far-sighted, visionary, proactive and enabling. Differences are evident in the treatment of climate change, safety standards, the implementation timeframe, the emphasis on structural protection measures, ecological processes and quality of life. There is a heavy emphasis on multifunctional land use and optimisation of benefits for all stakeholders.

The Deltacommissie Report was well received, and made a substantial contribution to the awareness of the impacts of climate change for the Netherlands. All the main recommendations were accepted by the Dutch Cabinet, and it was also 'warmly accepted by politics and in the media' (Verduijin *et al*. 2012).

One of the most striking differences when comparing the review processes of Australia and the Netherlands relates to the size and detail of the reports. The Deltacommissie (134 pages including appendixes) produced 12 recommendations, whereas the final Victorian Review (234 pages) produced 93 recommendations, and the Queensland Inquiry, with both reports taken together, was 916 pages long and produced 352 recommendations. Yet it could be argued that the Dutch process is far more likely to make a durable impact on the way flooding is managed. The fact that some of the Committee members were professional writers in addition to their primary areas of expertise (one with experience in journalism and another as a novelist) may also have enabled them to convey their message in a style that was engaging and influential (Deltacommissie, nd; Verduijin *et al*. 2012).

3.2 Climate change and other future threats

Climate change is the motivating force behind the Netherlands' Deltacommissie 2008 (see terms of reference above). It is also stated as being a primary consideration in the 2000 Water Policy, the Room for the River and river renaturalisation projects such as the Regge River. The Deltacommissie report analyses and quantifies the threat of climate change over a long timeframe (pp. 21-31), finding inadequacies in stream discharge capacity, reliability of structural defences, water quality and water security, ecological and social consequences, and economic consequences in terms of direct damages and impacts on tourism, navigation, agriculture and loss of land to the sea.

Other future threats, such as population increase and the location of economic growth centres, are also identified in the Deltacommissie report, contributing to the identification of appropriate adaptation measures and priorities (Deltacommissie 2008: 32). Future risk determinants such as demographics are largely ignored by Australian reviews.

Quantifying the threat (and deliberately using the worst-case scenario) enables appropriate measures to be identified that can be implemented incrementally over a 200-year timespan, enabling flexibility to be retained and cost-sharing by current and future generations (Deltacommissie 2008: 27, 41, 82). The review does not provide an exact blueprint plan of implementation, but it delivers a vision and broad strategies to achieve objectives.

Recommendations are provided for three time horizons: more concrete measures for immediate implementation by 2050; a clear vision for the period 2050-2100 and long term considerations beyond 2100 (p. 45). They are designed so that current adaptation measures do not compromise future adaptation options (for example, housing development should not be permitted in areas identified as potential water storage areas in case it becomes necessary to increase dam heights: Deltacommissie 2008: 52, 95). This ensures that flexibility to deal with future risks and uncertainty is retained. Clear vision with flexible temporal and local implementation is also used in the Regge revegetation project (de Boer and Bressers 2011*a*: 37) and 'Room for the River' (Dutch Government 2006: 10, 13, 16; Nijssen 2012).

The Deltacommissie (2008) identifies not only how to protect the Netherlands from the effects of climate change, but also how to create opportunities from it. Besides flood protection, opportunities are identified in water quality and availability (pp. 53, 57-59), agriculture (p. 27), recreation (pp. 39, 53, 71), scenic landscapes (pp. 39, 71) and biodiversity (pp. 39, 52), creation of space for housing and innovative building design (pp. 48, 52-53), and economic benefits including shipping (p. 71), energy generation (p. 39, 68, 73) and aquaculture (p. 73).

The Dutch head-on, opportunistic attitude to climate change risks contrasts with the Australian flood reviews that (both in terms of reference and report content) avoid climate change in a way slightly reminiscent of Basil Fawlty's injunction, 'don't mention the war'. When it is mentioned in Australian reviews, it is only in terms of a negative threat that increases municipal liability, reduces land value and introduces scarcely manageable uncertainty.

3.3 Drain or retain

In the Netherlands, rivers are highly modified. Since the mid-1800s, the Regge River has been canalised, re-engineered and regulated to ensure faster drainage for agriculture. Farmers in Victoria are currently calling for similar measures, to clear vegetation and increase channelisation in order to drain water away faster (Parliament of Victoria 2012: 114-118). It is therefore worth considering the reasons why the Netherlands is going to great trouble and expense to reverse this policy.

In the Regge River example, river modification has compromised many other river functions, including groundwater recharge and space for natural habitat. Water-storage capacity has been reduced by cutting out meanders and confining the river between narrow banks. This has left less space for floods to spill into, causing higher flood peaks. River modification has also compromised cultural heritage in some areas, with dry moats causing damage to castle foundations (de Boer and Bressers 2011*a*: 9, 43, 111, 145).

More recent Dutch water policy is holistic, in that it identifies adaptation measures that simultaneously address climate related issues of drought, flood and water quality. The Dutch strategy is to retain precipitation for as long as possible in the catchment where it falls, then (temporarily) store floodwaters, only draining them when capacity of 'retain and store' have been reached. This enables the replenishment of groundwater that has been depleted during drought and at the same time helps form a barrier to prevent salt water intrusion. It also ensures that flood problems are not simply transferred to those downstream (Dutch Government 2000: 32-33). The method used to achieve this is to allocate more space to water. Measures include increasing the size of active floodplains, lowering them (including through clay extraction for brick production) and restoring meanders and wetlands, and creating water-retention areas (Dutch Government 2000: 32–36). Another benefit of delaying the release of floodwaters would be to increase warning times for downstream communities.

The allocation of land for rivers is seen as a valid land use in itself, providing services such as flood control and water quality. The reservation of land for water services is not seen as under-using the land. Rather, the scarcity of land causes the Dutch to take a multifunctional approach, identifying compatible land use on land allocated to water, with agriculture, recreation, nature and flood management seen as good partners (see Dutch Government 2000: 31; Deltacommissie 2008: 39). This is a consistent feature of Dutch projects. In the Regge River example, land allocated to water management purposes is used to improve scenic value and attractiveness of the area for both residents and tourists, also boosting property values (de Boer and Bressers 2011*a*: 114). There are also co-benefits in nature conservation, cultural uses (e.g. art, festivals), preservation of heritage (e.g. the return of historic river boats), navigation, compatible agriculture (e.g. non-intensive grazing) and infrastructure such as bridges and bike paths (pp. 121, 132, 171, 176-177). In some areas, this multifunctional approach has also stimulated rural economies (pp. 139-148). Similar multifunctional objectives have been achieved in the Room for the River Programme (Nijssen 2012: 4-6).

3.4 Dykes and other structural measures

The case of the Netherlands is instructive, as it could be described as an extreme example of the use of levees, upon which so many Australian country towns depend.

To protect themselves from floods, the Dutch began constructing terps (artificial mounds to build upon) from about the ninth century. Dykes were built from the thirteenth century, both for flood protection and to reclaim land for agriculture. The process of land reclamation was facilitated between 1250 and 1600 by the introduction of windmills, enabling water to be pumped out of dyked areas. This also caused land to sink deeper as the soil dried out and the peat decomposed. As one author put it, 'the Dutch pumped themselves under the sea level' (Hallie and Jorissen 1997). Almost 60% of the Netherlands is susceptible to coastal and river flooding and roughly one quarter of the country is below sea level (van Alphen, 2013; de Boer and Bressers 2011*a*).

Over the centuries, the Dutch developed highly sophisticated water-management systems to protect themselves from flooding, not only in the form of dykes, sluices and drainage canals, but in management and funding mechanisms to maintain them. Described as the oldest democratic institutions in the Netherlands, Dutch Water Boards were formed from the thirteenth century to regulate and maintain flood defences (and, more recently, to ensure water quality). Water Boards have the right to levy taxes from people within their water board areas, giving them a high degree of independence from national politics and budgets (Lazaroms and Poos 2004). Dykes have been raised higher and higher, to retain ever greater volumes of water and development behind them has increased, leading to ever-increasing consequences should defences fail. While Dutch dykes may be in a different category to Australian levees, Smith's paradox[4] still applies (Smith 1998).

In a nation that has a history of tight structural control over water, it is interesting that the current approach centres on a recognition that dykes cannot be raised continually higher or the consequences of failure will mount (Dutch Government 2000: 27, 31). Moreover, the higher dykes rise, the higher the pumping costs to remove water from the areas they protect (Deltacommissie 2008: 67-69). Dyke reinforcement is a primary measure supported by the Deltacommissie (pp. 41, 47-49, 67). However, other measures are also used. The approach used in the 'Room for the River' program is to restore floodplains and allow floodwaters to spread over a wider area to reduce water depth. The activities to achieve this are still largely structural as it is not possible to simply remove dykes when the breach of primary dykes could inundate half the country; dykes are relocated inland, secondary water channels excavated and river beds, groynes and floodplains lowered. Forming separate compartments within dyked areas creates a secondary line of defence. For some polders (areas enclosed by dykes), partial lowering of dykes will enable water to flow through polders when water levels are high. As a consequence of having more space to spread, flood peaks will be reduced and safety will increase (Dutch Government 2000; Dutch Government 2012).

The Deltacommissie recommends a number of other structural measures. 'Closeable open' storm surge barriers are a flexible solution proposed to help to control water levels in estuaries.

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[4] Smith's 'levee paradox' describes the commonly observed phenomenon that when you protect areas from flooding by levees, it has the perverse effect of encouraging development behind them, increasing the potential for damage should levees be overtopped or fail (Smith 1998: 232–234).

These can be closed temporarily when high river discharge coincides with storm surge (in which case water retention areas would be used until floodwaters could safely be released). They could also be permanently closed if sea levels rise too high. In the meantime, having gates that are able to be open for most of the time enables natural tidal dynamics and salt/freshwater gradient that is good for habitat value, navigation and tidal energy generation. As barriers will act as dykes, they could also open up new areas for potential waterfront development (Deltacommissie 2008: 63-66).

Beach nourishment forms a large part of the Deltacommissie's coastal strategy. Sand is dredged from the continental shelf and spread on eroding flats or along dykes. This measure is currently used in Dutch coastal management. The report recommends massively increasing these efforts. Beach nourishment would be on such a large scale that beaches will not only keep pace with climate change sea level rise, but will actually widen the coast by about 1 km in a century. Benefits anticipated include increased safety for existing coastal resorts, more space for nature (coastal habitats being quite degraded over the last 150 years; see also de Boer and Bressers 2011*a*: 17), recreation and more land for development. However, the Committee recognises that there are energy efficiency, economic and ecological implications. Greater research into these aspects was recommended by the Committee. The possibility of creating offshore islands or reefs to protect the coast was considered, but beach nourishment was identified as the best option for reasons of cost-efficiency and because islands would have the potential to increase coastal degradation issues (Deltacommissie 2008: 52-55).

3.5 Reserving land for water

The Deltacommissie report stresses the importance of reserving land to restore the water storage capacity of the floodplain. It primarily recommends land purchase to achieve this, including reserving land under a permanent preference right, to allow purchase at such a time as the owner is prepared to sell it, and also to purchase strategic land positions when the opportunity arises (Deltacommissie 2008: 61). Unlike the Regge River project, where voluntary approaches were used, the Deltacommissie stresses that 'climate-proof' spatial planning in respect of building in unfavourable locations and early involvement of water managers 'must not be voluntary' (p. 96), though compensation is stipulated. The Dutch are not averse to compulsory measures with respect to water management if they are seen to be in the national interest (de Boer and Bressers 2011*a*: 31-32; Nijssen 2012: 4). With over 50% of the country at risk, they cannot afford to be.

The Regge River project used voluntary participation to reserve land. A particularly successful strategy was to purchase land in advance and then use it to exchange with land that was needed to realise the project. The advantage of this was that it enabled farmers to continue farming (overcoming resistance), and it prevented property owners from opportunistically elevating the price of their land (de Boer and Bressers 2011*a*: 117). Patience was particularly important in acquiring land, highlighting the importance of a durable, long-term strategy (p. 191).

Changing the designation of land to reflect its revised use was sometimes delayed as 'municipalities had quite often not made or updated *local land use plans* for their non- built-up-areas' (de Boer and Bressers 2011*a*: 30). However, the Regge project provided an opportunity to update land-use plans so they would be flexible and facilitate changes in land use designation from agriculture to 'new nature' by including an 'acceptable changes' layer in their land use plans (de Boer and Bressers 2011*a*: 163, 168). The plans (that identify acceptable changes) are subject to public scrutiny during initial drafting; however, once approved, 'acceptable changes' only need to go through the city council. Changes in land designation from agriculture to nature reduce property value by about one-third, but participation is voluntary and compensation is paid. In the case of the Regge project, calculations were done on the basis of the difference in land value over a 30-year period. Separate amounts were also provided for allowing the land to be used as a water- retention area in times of flood and for annual maintenance activities, as part of a Payment for Ecological Services scheme (de Boer and Bressers 2011*a*: 160-161, 175).

Land ownership requires ongoing land maintenance, and Dutch Water Boards sometimes transfer this role to other public bodies responsible for nature conservation. While the Regge River project purchased land, it also recognises that public ownership of the land is not necessary to achieve project objectives – the same objectives can be achieved by measures such as rezoning and land-use covenants (de Boer and Bressers 2011*a*: 175).

Australia does have examples of land acquisition to reduce vulnerability to flooding, but this has not been a standard practice. In Victoria's Lower Loddon catchment, properties most at risk of flooding have been purchased and resold with a covenant to restrict agricultural practices to more resilient dryland farming, and allowing properties to flood. In Grantham, Queensland, the whole community was relocated to higher ground after the floods, with plans to use the old site of Grantham for more compatible purposes. However, these are isolated examples that were initiated partly to help flood-damaged communities to recover, rather than being part of a durable nationwide (or state-wide) flood prevention policy.

3.6 Water safety

Australia tends to have a low tolerance to accidental death, including flood deaths. There is no political guidance on socially acceptable levels in the National Disaster Resilience Strategy, and no political debate. The Queensland Inquiry did not examine what the acceptable number of deaths should be for such an event. As an inquiry into a recent event where some communities lost many lives, this would have been insensitive. The Victorian Review (where no deaths occurred) suggests that emergency management needs to 'deliver an acceptable measure of safety and security to the community' without defining what this is.

The Dutch are more pragmatic in recognising that it is not possible to prevent all disaster-related deaths. They have conducted studies to assess the amount of money that goes into preventing traffic fatalities as a basis of determining the economically optimal safety level (Dutch Government 2008: 52). They have also compared safety standards for other types of incidents, commonly set at a probability of one in a million per year. The Deltacommissie proposes that this level should be applied as the minimum standard for each individual in every locality (within dyked areas). The Deltacommissie is also concerned that other water safety elements need to be incorporated into the minimum safety standard for each area, including societal or group risk (the probability of large numbers of simultaneous casualties), and flood damage, including both direct and indirect costs. The broad interpretation of 'water safety' is stressed, including cultural and environmental assets, societal disruption and reputational risk, among others (Deltacommissie 2008: 41-43, 96, 118-123).

The Dutch approach to water safety is highly engineered. Australia starts with the physical landform and, via flood studies, determines flood risk and (ideally) zones accordingly (if flood studies have been carried out and if they are incorporated in municipal plans). The Dutch, on the other hand, start from the premise that people are entitled to a safety factor and then ensure that appropriate measures are in place to give them this, primarily in the form of structural measures such as dykes, but also other measures such as spatial planning, early warning, response and contingency planning (Deltacommissie 2008: 41). Their land planning is not governed by whether or not land is within the 1 in 100 year flood line. Dutch measures manipulate that line, so that protection should be sufficient to defeat a 1 in 10,000 year event in North Holland (in view of the value of the interests that need to be protected). In other coastal regions, it is 1 in 4,000 year and for riparian areas the standard is 1 in a 1,250 year event (due to reduced damage resulting from fresh as opposed to seawater) (Deltacommissie 2008: 40). The reason for this difference could be attributed to Australia's low population density outside cities. This means that flood defences in most rural areas target 'high-value' assets like towns through isolated and *ad hoc* levee systems. The Netherlands is densely populated over its entire area, requiring more systemic management of floods along rivers.

The Deltacommissie reports that, according to a recent EU Directive, every river basin needs to have a flood-risk management plan (Deltacommissie 2008: 62). This is interesting in that the flood plans are to be based on geographic catchment boundaries, rather than artificial administrative boundaries, as is often the case in Australia.

3.7 Conclusion of ‘differences’

For the Dutch, the 1990s flood events revealed that business as usual in the form of fighting against floods with ever taller dykes and other structural measures would be insufficient to deal with new emerging threats; analysing recent floods and reactively patching up holes in existing frameworks and organisations would not make the Netherlands safe for the longer term. This resulted in a fundamental reassessment of existing water policy and centuries-old water management systems. Central to their revised approach is floodplain restoration, with its multiple benefits – a measure that received little, if any, attention in Australian reviews (although Victoria’s flood mitigation review, yet to be released, may cover this to some degree).

4. Assessment of the applicability of the Netherlands approaches to Australia

Today, roughly a quarter of the Netherlands is below sea level, its lowest point being 6.74m below sea level at Nieuwerkerk. 65% of the country’s wealth is located on floodprone land protected by dykes. This makes the Netherlands extremely vulnerable, to the extent that flood risk is a supreme issue for national security and large funds are available for investment in flood measures. The national scale of the threat also explains why the Netherlands uses a much more conservative flood likelihood standard than other countries, to compensate for the extreme consequences should a flood happen (Deltacommissie 2008; Dutch Government 2012).

In Australia, a significant amount Australian wealth is located in coastal areas and is threatened by flooding as a result of sea level rise (Australian Government 2009). Inland flooding is also likely to become more severe. However, flooding is unlikely to be a national security issue as it is in the Netherlands. In Australia – the country with the most natural variability of weather patterns in the world – some find the El Niño-La Niña cycle of greater overall significance than perceived gradual changes in climate change. Funds to implement structural measures on the scale of the Netherlands are unlikely to be made available, and planning for rare events on the scale of 1 in 10,000 years (for the Netherlands north coast) or 1 in 1,250 years (for most riparian areas) are unlikely to become the standards adopted for residential development in Australia.

Some of the measures used by the Dutch are inappropriate for Australia. It is difficult to see how beach nourishment would be acceptable as a measure to counteract rising sea levels and storm surge, given the damage it would do to coastal ecosystems. In Australia, use of more natural mangrove ‘bioshields’ may be a more appropriate measure. Use of dykes along riverbanks in flood-prone cities such as Brisbane is equally unlikely to be popular, as well as expensive (this measure was considered in the Brisbane's 2011 flood review and discarded – see Arnison *et al*. 2011: 62).

Despite this, the Netherlands has some valuable lessons for Australia to help it manage flood. There is potential for the 'retain–store–drain' and 'room for the river' approaches, ensuring more land is allowed to flood by removing or setting back floodplain levees to reduce their severity. Such measures may have added advantages, enabling replenishment of groundwater resources to counteract prolonged drought, the flipside of climate change. There are advantages in the co-benefit approach to land use where space is scarce, this providing optimal outcomes to stakeholders and enabling cost- sharing of projects by multiple sectors.

The importance of considering cultural heritage in relation to flooding is evident in the Regge River project and is also underlined in the Deltacommissie report (p. 37). Many of Australia's earliest European settlements were sited in the most vulnerable flood-prone confluences, and Aboriginal heritage (e.g. coastal shell middens) is also likely to be threatened by flooding related to sea level rise (Smith 1998; Pearson 2007). The resilience of cultural heritage was not an aspect covered in Australian flood reviews, but following the Dutch example, this is something that should be given greater consideration in Australian flood-management strategies.

The Dutch do not skirt politically difficult issues such as climate change and acceptable flood mortality. By putting figures on the table, they are able to open up debate on these issues to determine what needs to be done about them. The solutions they have come up with, like the use of dykes, or the adoption of a flood death probability of 1 in a million per year for each individual as a minimum standard, may not be the solutions Australia adopts. However, the political courage to face such issues represents leadership from which Australia could learn.

Australia's disaster review process could also merit examination. Australia's flood reviews were incredibly detailed and lengthy (some flood professionals confessed to not having had time to read them). A review's analysis of what can go wrong in a flood event is instructive, but the same issues come up each time there is another flood (Handmer, pers. comm.). This raises the question of whether the current review approach is an effective one. The review process tends to retrospectively patch up holes revealed by past events. Many failures in the 2010-11 floods were the result of human error rather than inherently bad systems, and many successes were entirely due to the unusually skilful efforts of individuals in the absence of administrative processes. A new set of faces and circumstances during the next flood will reveal new and slightly different gaps in the system. This approach is not necessarily effective in preventing future disasters – certainly not for nationwide floods that might only happen every 10-30 years. The Deltacommissie, because it did not have to review any specific event, was free to focus on addressing flood risk in the long term. The firm vision and flexible implementation over a 200-year timeframe are remarkable. Moreover, the manner in which it has been framed and the accessibility of its writing style have resulted in a document that is influential and arguably more widely read than its Australian counterparts.

An examination of documents from the Netherlands reveals strong spatial planning mechanisms imposed from the national level (with flexible local implementation). Water management is clearly seen as an issue of national concern, as any under-estimation or inaction in addressing future flood risk could have severe consequences. Such a national approach is harder to achieve in a federated state like Australia. Under Australia's constitution, state governments have primary responsibility for natural resources. The Federal Government's role is limited unless it is invited by state governments or chooses to legislate using its powers to regulate corporations or to fulfil national obligations under treaties, including those related to wetlands and climate change. However, according to the Council of Australian Government's National Disaster Resilience Strategy, greater focus needs to be given to prevention, and not just response. The implementation of this strategy could provide an avenue to develop a more cohesive approach to development planning. The use of PES schemes and a variety of land-reservation methods that enable appropriate land use and multifunctional approaches could all be used to improve development outcomes and Australia's flood resilience.

Publication 3 preamble

Wenger, C, 2013, Climate change adaptation and floods: Australia's institutional arrangements, National Climate Change Adaptation Research Facility, Gold Coast.

Publications 1 and **2** provided an understanding about problems with traditional approaches to flooding. They highlighted a need for long term development planning for future flexibility. They also offered insight into innovative approaches to flood management that make use of the flood buffering capacities of natural ecosystems. The potential for ecosystem based approaches to delay floods (and increase warning times) has implications for climate change as intense precipitation events are likely to result in more flash floods.

Publication 2 revealed the types of institutional arrangements that support the use of ecosystem based approaches. These include a catchment approach to flood management, integrated water resource management (enabling joint funding and win-win solutions across sectors), and a long term view of spatial planning. In particular, planning needs to allow flood compatible land uses. This can involve land use change, sometimes requiring relocation, and land reservation to address long term future risks.

Implementation often creates challenges and Dutch sources are instructive about how they have overcome some of these obstacles. In some cases, new institutional mechanisms such as the Delta Fund have been established for this reason. In order to determine whether Australia could adopt similar approaches it is important to have a thorough understanding of Australia's existing flood management arrangements. This is the aim of **publication 3**. A particular emphasis of this publication is provisions for flood prevention /mitigation, including development planning and ecosystems based measures and the incorporation of flood prevention ('betterment') into recovery funding, a lesson from the USA case study.

Publication 2 (section 6.2.2) provides an interesting Dutch perspective on flood management, contrasting the 'Anglo-Saxon style' (where responsibility for flood safety is placed on the individual/local community) with the 'Continental style' (where the government takes responsibility). It suggests that the Anglo-Saxon style can lead to a disjointed approach with communities having different safety standards and a greater emphasis on emergency response and recovery mechanisms. The Dutch analysis of Anglo-Saxon versus Continental management styles is also suggestive of arguments by some writers that disaster resilience is a manifestation of neo-liberalism (see **publication 7**). **Publication 3** covers Australia's National Strategy for Disaster Resilience and associated program and funding arrangements. These place great emphasis on shared responsibility and self-reliance.

The scope of **publication 3** was restricted to arrangements that were in place at the time of the 2010-11 floods. It is thus a 'snapshot in time' and fast became out-of-date in an environment of rapid change to emergency arrangements. However, its enduring contribution is that it describes management arrangements that probably contributed to the disaster and its cost. From the perspective of this thesis, this is the institutional context within which policy transfer from overseas would need to take place.

Publication 3 findings were communicated in a conference paper and presentation at the 2014 Floodplain Managers Association Conference. This summary incorporated some legal and administrative changes that had happened since the 2010-11 floods (**Appendix 5** of this thesis).

Climate change adaptation and floods: Australia's institutional arrangements

Preface

Climate change adaptation and floods is a case study that contributed to a broader climate change adaptation project. The case study used project methodology developed by Karen Hussey, Steve Dovers and Richard Price. Details of the umbrella project are:

> Hussey, K, Price, R, Pittock, J, Livingstone, J, Dovers, S, Fisher, D and Hatfield-Dodds, S 2013, Statutory frameworks, institutions and policy processes for climate adaptation: Do Australia's existing statutory frameworks, associated institutions and policy processes support or impede national adaptation planning and practice?, National Climate Change Adaptation Research Facility, Gold Coast, 193pp.

The case study also drew upon work undertaken as part of a second NCCARF project under its synthesis and integrative program (referred to in this paper as the SIRP Report):

> Wenger, C, Hussey, K and Pittock J 2013, Living with floods: Key lessons from Australia and abroad, National Climate Change Adaptation Research Facility, Gold Coast, 267pp.

The author would like to thank Jamie Pittock, Karen Hussey and Richard Price for valued feedback on the initial draft.

2. Objectives of the research[5]

2010-2011 saw some of the biggest flood events in Australia's history, with approximately 80% of Queensland declared a disaster zone and extensive flooding in other eastern states, notably Victoria. Flooding is Australia's most expensive natural hazard and the Federal Government allocated 5.6 billion in recovery funding to Queensland alone, primarily to restore public infrastructure (BITRE 2008; Gillard 2011*b*). Climate change scenarios predict an increase in intensity and frequency of flooding, potentially exposing Australia to even greater damages in the future. Floods are thus a key area for improving adaptive capacity.

The large scale of events, the number of lives lost and the scale of the damage incurred prompted numerous inquiries and review processes by different governments and organizations. Flood research for a related project by the same author analysed four Australian flood reviews[6] to determine if they offered any lessons for climate change adaptation (Wenger

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[5] The executive summary has been omitted in the interests of space. The summary formed the basis of a conference paper and presentation delivered to the annual Floodplain Managers Association conference in 2014 to communicate and update this work (Appendix 5 of the thesis).

[6] Australian reviews studied for the SIRP report include: the Queensland Floods Commission of Inquiry (referred to in this report as the QFCI); the Victorian Review of the 2010-11 Flood Warnings and Response (referred to in this report as the Comrie Review); the Brisbane Flood January 2011: Independent Review of Brisbane City Council's Response; and the Environment and Natural Resources Committee Inquiry into Flood Mitigation Infrastructure in Victoria (referred to in this report as the ENRC Inquiry). Other reviews were referenced but not studied in depth.

et al. 2013). The project identified inadequacies in institutional and regulatory arrangements, development planning and funding mechanisms and overwhelmingly pointed to the need for improvements in non-structural measures, particularly in the preventative phase of emergency management. It also found that adaptive approaches that are proving successful and cost effective overseas are largely unknown in Australia, and would have difficulty being implemented under current arrangements.

Accordingly, this paper will explore flooding from the perspective of government function to determine:

- current policies and institutional arrangements in place to address flooding; and
- the types of reforms that would be required to reduce Australia's vulnerability to flooding in the future.

Floods should not be seen merely as disasters. Australia's carryover water storage system depends on them. Managed well, flooding can replenish groundwater, restore ecosystems and boost economies. How Australia manages floods will be vital for its adaptation to other climate change impacts such as drought.

Prevention, Preparation, Response and Recovery, otherwise known as PPRR, is the standard emergency management framework currently used in Australia (EMA 2004; COAG 2011). Its advantage, as well as being widely understood by flood managers, is that it divides disaster management into temporal phases. Research indicates that proactive intervention in the prevention stage, is more effective and cost efficient than interventions at later stages (BTRE 2002; Wenger *et al*. 2013). The emphasis of this paper is therefore on flood prevention.

Adaptation to climate change in the context of flooding can encompass many different strategies, including protect, accommodate and retreat options. In terms of protection, structural measures such as constructing flood walls, dams and levees are options often called upon, though in the long run, this approach can be maladaptive, having adverse environmental impacts, transferring problems elsewhere or leading to a false sense of security that increases vulnerability when defences are overcome. Another approach is to ensure land use and/or building design that is compatible with flooding. For this to be effective under climate change conditions, it is important that future risks are assessed and incorporated into planning processes. Where accommodating floods is not feasible, relocation can be used to remove people from hazardous areas, and this can be combined with land use changes so that affected areas can continue to be used.

Other adaptation strategies can include improved preparation and response mechanisms for large scale emergencies that enable joined up capacity across different agencies, coupled with improved community awareness and self-sufficiency. Many of these can be hard to sustain during extended periods between large flood events. Moreover, some note that non-structural methods of prevention, such as land use planning and building standards, are more effective than attempting to modify human response behaviour through public education, warning systems and emergency response (Comrie 2011: 191). The emphasis of this paper is therefore on identifying the drivers and barriers to more proactive prevention approaches to flood management.

3. Research activities and methods

The case study used methodology used in the umbrella project, *Statutory frameworks, institutions and policy processes for climate adaptation* (Hussey *et al*. 2013). This entailed assessing institutional arrangements for flooding according to seven institutional mechanisms (covered in the 'results' section of this paper), and assessing their adaptive characteristics according to four criteria (covered in the 'discussion' section of this paper).

The seven institutional mechanisms include:

Intergovernmental functions: These are formal agreements between governments to work towards specified objectives. The Council of Australian Governments, comprising the heads of federal, state and territory governments, represents the pinnacle of such frameworks. At the issue level, agreements and frameworks include the Murray Darling Basin Agreement, National Water Initiative, and the National Competition Policy among others. Usually these agreements and frameworks are underpinned by legislation and supporting institutions.

Intra-governmental functions: These are initiatives within a tier of government, either federal or state, which imposes a common platform of accountability, such as reporting on sustainability or social inclusion, or promotes or requires cross agency cooperation in dealing with a particular issue. The joint administration of the Natural Heritage Trust and Caring for our Country initiatives between SEWPAC and DAFF is an example of this.

Regulation by prescription: These are mandatory (legal) requirements that must be met under specific laws/legislation. They are the primary instrument of government agencies to achieve agency objectives.

Planning processes: These are strategic and administrative procedures and modus operandi by which agencies prescribe and authorize desired action in anticipation that such action will provide public benefit or avoid public dis-benefits.

Funding functions: These are incentive programs or investment initiatives that provide subsidies or co-investment as a means of stimulating the uptake of particular actions.

Information and analysis functions: These are publicly funded initiatives aimed at enhancing the understanding of phenomena (basic research) and how to deal with these (applied research) and at enhancing stakeholder understanding of the consequences of phenomena and the means of responding (education and awareness).

Market arrangements: These are instruments of government that influence the way in which industry actors behave in various markets. Examples include water trading and trade policy.

The four adaptive characteristics assessed include:

Clarity of purpose: Requires clear definition and understanding of problems at a system level so that we can address root causes and not just symptoms.

Diversity: Requires a diversity of ideas, skills and resources, a diversity of views, innovation, flexibility in problem solving, and wide inclusion of stakeholders in a purposeful and structured fashion.

Connectivity: Requires institutional (including community) networks that are not susceptible to collapse due to one part failing; effective use of resources; community ability to organise itself; appropriate leadership; spare capacity; and some duplication of functions and overlapping of institutions.

Integration and feedback: Requires a holistic consideration of issues and realistic consideration of scale, accounting for the full range of interactions between humans and ecosystems. It also requires resources to monitor and to promote debate and learning.

The case study primarily relied upon literature review. Due to the nature of the topic, government documents form a large proportion of source material, including flood reviews, policy documents, agreements and funding reports. Where relevant, this report also draws upon work the author carried out for the NCCARF project, Living with floods: key lessons from Australia and abroad (referred to in the body of this work as the 'SIRP report'). The methodology of the SIRP report included literature reviews for both Australia and overseas, and interviews with six end-user groups.

The scope of this paper is limited to the institutional arrangements in place at the time of and immediately following the 2010-11 floods, and should be regarded as a 'snapshot in time'. Reforms that take place as a consequence of the floods may be covered in future work.

4. Institutional landscape for floods in Australia

Under Australia's constitution state governments have primary responsibility for natural resources and flood management is therefore the domain of state and local governments. The Federal Government's role is limited unless it is invited by state governments or chooses to legislate using its powers to regulate corporations or to fulfil national obligations under treaties, such as those related to wetlands and climate change. The Federal Government has therefore avoided a coercive approach to activities that relate to land use and development planning. However, as discussed in section 5.5, more coercive tactics have been used overseas by states with similar constitutional limitations.

Table 3.1 provides an outline of the institutional landscape for floods in Australia. The table is not exhaustive but it shows that Federal Government involvement in flood prevention is primarily confined to exhortative and cooperative styled policy instruments such as intergovernmental agreements, funding arrangements and the provision of information, standards and guidelines (Handmer and Dovers 2007: 110-120). The role of state and territory governments is to develop policy, strategies, tools and legislation, while local governments implement them. States can also directly approve development, for example states can have separate development legislation for projects of regional or state-wide significance.

The business sector and individuals also have a role to play in flood management, for example, through private land management practices, insurance, use of flood resilient design and purchase decisions. Some of these aspects are addressed more fully in Case Study 4 on market mechanisms.

Table 3.1: Key statutory and institutional frameworks that relate to flooding.[7]

Government Level	Responsibility	Legislative/ Policy/ Coordination Mechanisms	Responsible government authority/institution
Federal	Coordination across jurisdictions where there is a national interest Provision of information, standards, best practice guidance Provision of funding to enable national objectives to be met	National Strategy for Disaster Resilience (adopted by COAG 13.2.11) National Disaster Resilience Framework (endorsed by MCPEM-EM 20.11.09) National Partnership Agreement on Natural Disaster Resilience (2009/10 - 2012/13) Australian Emergency Management Arrangements (endorsed by MCPEM-EM 6.11.08) Climate Change Adaptation Action Plan (endorsed by MCPEM-EM 20.11.09) Enhancing Disaster Resilience in the Built Environment Roadmap National Risk Assessment Framework (endorsed by AEMC in 2007) Australian emergency management manual series Natural Disaster Relief and Recovery Arrangements National Flood Risk Information Program	Council of Australian Governments (COAG) Standing Council on Police and Emergency Management (SCPEM)[8] Australia-New Zealand Emergency Management Committee (ANZEMC)[9] National Flood Risk Advisory Group (NFRAG) Land Use Planning and Building Codes Taskforce Attorney-General's Department Emergency Management Australia Australian Emergency Management Institute Geoscience Australia

[7] Note this table focuses on policy and institutional frameworks that relate to the prevention of flooding rather than emergency response.
[8] Previously the Ministerial Council for Police and Emergency Management (MCPEM).
[9] Previously the National Emergency Management Committee (NEMC), or the Australian Emergency Management Committee (AEMC).

Government Level	Responsibility	Legislative/ Policy/ Coordination Mechanisms	Responsible government authority/institution
Federal (cont.)		Flood Warning Service Program	Bureau of Meteorology
		Building Code of Australia	Australian Building Codes Board
		Water for a Healthy Country Flagship	CSIRO
		Floodplain Management in Australia: best practice principles and guidelines (SCARM)	Department of Climate Change and Energy Efficiency (DCCEE)
		National Climate Change Adaptation Framework (agreed by COAG in 2007)	National Climate Change Research Facility
		Climate Change Adaptation Program	
		Australian Rainfall and Runoff Revision Project	
		(Engineers Australia, funded by DCCEE)	

Government Level	Responsibility	Legislative/ Policy/ Coordination Mechanisms	Responsible government authority/institution
State/ territory[10]	Enactment of planning and development legislation and development of planning policies and instruments Development approval for some projects of state significance (e.g. regional development projects) Coordination and funding of regional or catchment based approaches Provision of expertise and resources to local governments to enable them to meet legal obligations and policy objectives	*Catchment and Land Protection Act 1994 (Vic)* *Water Act 1989 (Vic)* *Planning and Environment Act 1987 (Vic)* Victoria Planning Provisions *Coastal Management Act 1995 (Vic)* *Building Act 1993 (Vic)* Victoria Building Regulations 1994 *Local Government Act 1989 (Vic)* *Emergency Management Act 1986 (Vic)* Climate Change White Paper (Vic) Emergency Management Manual Victoria Victoria Flood Management Strategy Victorian River Health Strategy Victoria Flood Database *Water Act 2000 (Qld)* *Coastal Protection and Management Act 1995 (Qld)* *Building Act 1975 (Qld)* *Sustainable Planning Act 2009 (Qld)* Queensland Planning Provisions State Planning Policy 1/03 (Qld) Queensland Development Code 'Satellite' planning legislation (various) *Building Regulation 2006 (Qld)* *Local Government Act 2009 (Qld)* *Disaster Management Act 2003 (Qld)* Climate Change Adaptation for Queensland: issues paper Planning for Stronger, More Resilient Floodplains (Qld) Resilience and Rebuilding Guidelines (Qld, various) Queensland Coastal Plan	Catchment Management Authorities (Vic) Natural Resource Management bodies (Qld) Department of Sustainability and Environment (Vic) Department of Planning and Community Development (Vic) Department of Primary Industries (Vic) Department of Community Safety (Qld) Department of Housing and Public Works (Qld) Department of State Development, Infrastructure and Planning (Qld) Department of Local Government (Qld) Queensland Reconstruction Authority Department of Environment and Heritage Protection (Qld) Department of Natural Resources and Mines (Qld) Queensland Climate Change Centre of Excellence Victorian Centre for Climate Change Adaptation Research Emergency Management bodies (various)

[10] For state government mechanisms, Victoria and Queensland are provided as examples

Government Level	Responsibility	Legislative/ Policy/ Coordination Mechanisms	Responsible government authority/institution
Local	Undertaking flood studies (NB, in Victoria this is a CMA responsibility) Development of planning schemes that align with state legislation and policy to enable appropriate land use and development controls Development application decision-making Emergency management responsibilities at all stages of PPRR	Planning schemes and policies State and federal local government associations Coastal Councils Adaptation Taskforce (Qld) Regional Organisations of Councils (ROCs) Other local government alliances, for example, the South East Councils Climate Change Alliance Incorporated (Vic) and Sydney Coastal Councils Group (NSW)	Local Councils

5. Results of flood institutions analysis

5.1 Intergovernmental Function

Disaster management is subject to many intergovernmental agreements and institutional arrangements. In recent times, the focus has been on resilience, a broad term that covers all aspects of disaster management[11] and that can be applied to communities, management systems and infrastructure. This moves away from 'mitigation', which became the focus following the 2002 report to COAG on "Natural Disaster Management in Australia: reforming mitigation, relief and recovery arrangements" (DOTARS 2004).

5.1.1 National Strategy for Disaster Resilience

Currently, the most influential intergovernmental mechanism for emergency management is the *National Strategy for Disaster Resilience* (NSDR), formally adopted by COAG in February 2011. The NSDR attempts to drive a cooperative, national approach to natural disaster management, using 'resilience' as its motivational power, and emphasising shared responsibility for emergency management between governments, communities, businesses and individuals. The aim is to develop partnerships, understanding of risks and long term behavioural change. More practically, the strategy provides seven key actions, each with a number of priority outcomes. The strategy is broad in scope, covering leadership, risk assessment, empowerment, awareness, partnerships, prevention and response capacity. Future drivers such as climate change and development pressure are provided as the rationale for developing the strategy (COAG 2011).

The Standing Council on Police and Emergency Management (SCPEM), a high level body that reports direct to COAG, has been assigned responsibility for implementing the NSDR (EMA 2012). The SCPEM is serviced by the Attorney-General's Department and supported by a number of other committees and bodies. To address issues associated with flooding, the National Flood Risk Advisory Group (NFRAG) reports to Australia-New Zealand Emergency Management Committee (ANZEMC), which reports to the SCPEM and thus to COAG (see Table 3.1).

The SCPEM (and its predecessors or committees) have been responsible for producing many other key documents to guide intergovernmental natural disaster arrangements. These include the *National Disaster Resilience Framework*, the *Australian Emergency Management*

[11] In Schedule A of the National Partnership Agreement on Natural Disaster Resilience (2009), resilience is defined as "the capacity to prevent/mitigate, prepare for, respond to and recover from the impacts of disasters".

Arrangements and the *Climate Change Adaptation Action Plan*. These documents complement each other and should be considered together rather than in isolation.

A number of intergovernmental funding agreements and arrangements are also in place, including the *Partnership Agreement on Natural Disaster Resilience* and the *Natural Disaster Relief and Recovery Arrangements* (both discussed in the Funding Mechanisms section). Mechanisms that are more response-oriented, such as the *National Catastrophic Natural Disaster Plan*, are not the focus of this paper.

5.1.2 Australian Emergency Management Arrangements (AEMA)

Under Australia's constitution, responsibility for emergency management rests with state/ territory governments. However the AEMA makes it clear that this is carried out in partnership with other government levels and community sectors. The arrangements are not limited to natural hazards. The AEMA clarifies the roles and responsibilities of different levels of government, the community and specific sectors, such as insurance, development planning and construction industries, infrastructure providers and the media. The Arrangements specify activities that are expected to be undertaken at all stages of prevention, preparedness, response and recovery. The AEMA does not cover climate change as it focuses on responsibilities rather than strategies (AGD 2009).

5.1.3 The National Disaster Resilience Framework

The *National Disaster Resilience Framework* appears in some respects to be a precursor of the NSDR and the framework was endorsed by MCPEM-EM in November 2008, a year before COAG resolved that a national strategy needed to be developed. The framework specifically includes climate change and other future risks as a rationale and covers the whole range of PPRR, integrated nationally across sectors (MCPEM-EM 2008).

5.1.4 Climate Change Adaptation Action Plan

In November 2009, the Council endorsed a *Climate Change Adaptation Action Plan* (MCPEM-EM 2009). This highlighted the need for adaptation to minimise projected impacts of climate change for the emergency management sector. It includes nine key strategies that aim to achieve a national, integrated approach; improved incorporation of climate change information into emergency management; and integration of climate change into settlement, land use planning and development decisions at the local level. To date, not many of these strategies appear to have been implemented. For example, the only reference to the proposed strategy #1, "National Statement on Climate Change Adaptation and Emergency Management" appears to be in the *Climate Change Adaptation Action Plan*. The proposed strategy #9 "National Guide to Climate Change and Emergency Management in Land Use Planning" is presented as a single webpage on the Australian Emergency Management Institute website that contains eight dot points of links that "lead to information on the impacts of climate change and current guidelines on accounting for these impacts in land use planning policies". Of these eight links, four do not work and some provide only the homepage of relevant organisations. When accessed (22nd October 2012), the page recorded that it had last been updated on 17th October 2011 (AEMI 2012*a*). The *Climate Change Adaptation Action Plan* thus appears highly relevant at first glance but implementation is patchy.

5.1.5 Enhancing Disaster Resilience in the Built Environment Roadmap

The SCPEM is currently developing the 'Enhancing Disaster Resilience in the Built Environment Roadmap', a collaborative attempt across jurisdictions to improve land use planning and building regulation in the context of emergency management. Should this be endorsed it will be notable for being one of the rare high level intergovernmental agreements to tackle this aspect of disaster prevention. Little can be said about the Roadmap as at the time of writing it had not yet been made publically available. However, it is expected to cover integrated legislation, process enhancement, comprehensive data and mapping, collaborative vendor disclosure, governance partnerships, inter-jurisdictional collaboration and lifelong education and training on natural hazard management (AEMI 2012*b*: 7-8).

5.1.6 The National Climate Change Adaptation Framework

The Federal Government's climate change strategy is built on 3 'pillars', including mitigation (reduction of emissions), adaptation (to climate change that cannot be avoided) and contribution to the collective global response (DCC 2010). The *National Climate Change Adaptation Framework* was agreed to by COAG in 2007 and it covers natural disaster management (COAG 2007). The Framework's key strategies in the context of emergency management include the need to improve knowledge of the nature and extent of changes to hazards such as flooding and the incorporation of this knowledge into planning for natural disaster management through programs such as the (then) Natural Disaster Mitigation Program. It also recommends awareness raising among communities and response agencies about the impacts of climate change. Through a national partnership agreement, the Natural Disaster Resilience Program appears to be working towards these objectives by funding risk assessments and community resilience (see funding mechanisms section). It is not clear to what degree preventative measures are likely to be put into place as a consequence of these assessments or how effective awareness raising activities are in achieving long term increased community responsibility or behavioural change.

'Settlements, infrastructure and planning' is another highly relevant strategy in the Framework. In its list of actions it includes, "revision of planning systems including revision and development of codes, standards and guides to increase resilience to climate change". Initiatives that address development planning, as exemplified in this framework, often appear in parallel with emergency management rather than being integrated into them. This is not necessarily an issue if outcomes are achieved but it could have the effect of reducing the emphasis on disaster prevention in intergovernmental mechanisms such as the National Partnership Agreement on Natural Disaster Resilience (see funding mechanisms).

5.1.7 The Australian Building Code Board

The Australian Building Code Board (ABCB) is a joint initiative of all three levels of government in Australia, with the Board's website describing it as "a regulatory reform vehicle for COAG". It was established by an inter-governmental agreement in 1994, which was renewed in April 2012 (ABCB 2012*a*). The Board develops (minimum) national standards for building and plumbing, aiming to ensure (in order of priority), safety, health, amenity and sustainability. At the time of the 2010-11 floods, these did not include standards that addressed flooding (Comrie 2011: 193; QFCI 2012: 212). Apart from the ABCB's *National Construction Code*, the Federal Government's involvement in facilitating improved land use and development planning to minimise damage from natural disasters is relatively recent, justified by an anticipated increase in exposure to natural hazards and corresponding escalating costs of recovery. Building codes will be covered in more detail in later sections of this paper.

There are thus a number of different intergovernmental mechanisms applicable to flooding and adaptation to climate change. They are comprehensive in that they seek to address knowledge gaps about climate change related flooding, and to integrate this knowledge into planning, professional training and awareness raising. Measures known to reduce exposure to flooding, such as improved development planning, are receiving high level attention. Whether or not these mechanisms will translate to improved management on the ground, it remains to be seen. Discussion in other sections of this paper suggests that to ensure success, many barriers would need to be overcome, including the non-mandatory nature of many current provisions relating to flooding, disincentives such as badly targeted flood relief, conflicting development policy objectives, planning tools that are inadequate to address future risks and inadequate resourcing.

5.2 Intra-governmental function

Intra-governmental mechanisms for flooding operate at all levels. These collaborations are important in ensuring a whole of government approach and are often very efficient in terms of making use of skills and resources from other agencies, pooling financial resources, and providing a focus for common concerns that might otherwise be overlooked due to competing priorities (this seems particularly relevant for the local government example, below). However, to be effective, they require policy leadership to ensure all agencies involved are working together, rather than working to conflicting agendas. This section provides an illustrative example of intra-government interactions for each level of government.

5.2.1 Implementation of the NSDR

The NSDR is a focus for much intra-governmental activity on flooding at the federal level. As an example, the Bureau of Meteorology, Geoscience Australia and Emergency Management Australia are all involved in implementing the National Flood Risk Information Project (NFRIP), which contributes to the NSDR by improving the quality and availability of flood risk information. Geoscience Australia leads the technical and implementation aspects of the project and has developed a database of flood studies as well as national guidelines for flood risk information. The Attorney-General's Department (housing Emergency Management Australia) has the policy lead, while the Bureau of Meteorology also contributes information to flood studies and provides historical data. This collaborative approach appears to make good use of different agency strengths (Geoscience Australia 2012).

5.2.2 Applying flood controls at the state government level

The management of flood prevention can involve interactions between multiple state departments. Administered by the Department of Community Safety (DCS), *State Planning Policy 1/03* (SPP 1/03) is the most important state planning instrument for considering flood risk in Queensland. However, DCS is not the only department involved in the application of the policy, and the assessment of local planning schemes has not favoured the inclusion of flood provisions.

Queensland's planning schemes are subject to review by a number of state agencies before a decision is made by the Minister for Local Government and Planning about whether to approve them. Investigation into these review processes by the Queensland Floods Commission of Inquiry found interactions between these agencies to be dysfunctional (QFCI 2012). The Department of Environment and Resource Management (DERM)[12] is responsible for advising DCS, on request, about the adequacy of any proposed planning scheme. It advises on a scheme's compliance with *SPP 1/03*, its flood map and on the proposed 'defined flood event' (if an event of greater frequency than a 1:100 year event is proposed). However, the DCS did not routinely seek this advice, even in the case of Brisbane's planning scheme which failed to identify a defined flood event. Recommendations by DCS to ensure compliance with *SPP 1/03* for significant flood prone areas such as Brisbane and Emerald appear to have been routinely

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[12] Note that since the inquiry report was published, Queensland state government departments have been restructured.

disregarded by the Department of Local Government and Planning (DLGP), resulting in non-compliant planning schemes. Issues raised by the DCS about a number of planning schemes included lack of or insufficient flood mapping and failure to nominate a defined flood event. In the case of Brisbane's planning scheme, the DCS reiterated its concerns about non-compliance on 16 occasions, 12 of these after the 2010/11 floods. The reasons why DLGP rejected DCS recommendations could not be explored by the Inquiry due to lack of documentation. The QFCI report also noted that prior to the Inquiry, the DCS had not realised the extent to which its advice had been disregarded. This raised serious questions about administrative procedures and accountability measures.

The SIRP report identified conflicting policy objectives as contributing to difficulties in applying flood controls. This is likely to be a root cause in the failure of the Queensland approvals process. Some key, interrelated policy conflicts include:

- affordable housing objectives versus safety through reduced exposure to floods;
- short term economic gains from development versus long term cost of exposure to flooding;
- population pressure that pushes development into unsuitable areas;
- high cost of developing flood free land beyond existing townships; and
- environmental objectives (e.g. to reduce the urban footprint via infill) which reduces the availability and affordability of flood-free land within urban areas.

Portfolios responsible for conflicting objectives in the context of flood risk include community safety, emergency management, development planning, climate change and environment and natural resource management. Adaptation to increased flood risk needs a consistent, whole-of-government approach if it is to be successful.

Many of the policy conflicts identified are directly or indirectly related to upfront development costs and housing affordability. Climate change studies suggest that future flooding risks to disadvantaged groups "would increase by factors of three to 20 – significant sections of the population could be blighted" (Galloway 2009: 6). The provision of cheap (but risky) residential sites to disadvantaged groups who can't afford to buy premium, flood-free land only increases their long term vulnerability to climate change.

State and local governments have the responsibility for providing affordable housing, and yet it is the Federal Government that provides the majority of relief and recovery funding. Unless the financial liabilities for bad development decisions rest with those making them, there will be little incentive to change.

If governments determine that affordable housing is needed, they need to weigh up the most cost effective and appropriate ways of achieving this. Subsidising the long-term costs of affordable housing through increased expenditure on disaster relief and recovery may not prove to be the most cost effective solution. It is not consistent with the 'community resilience' approach. Neither is it a just solution in terms of the psychological impacts people will be exposed to.

5.2.3 Local government alliances

At the local level, local government alliances have formed in some states that aim to address regional climate change impacts. Initially funded by the Victorian Government, almost the entire State of Victoria is covered by ten such alliances (NAGA and SECCCA 2012). Similar alliances are also found in NSW.

As an example, Sydney Coastal Councils Group is a Regional Organisation of Councils (ROC) comprising fifteen local governments[13]. Its stated aim is "to promote cooperation between, and coordination of actions by Member Councils on issues of regional significance concerning the sustainable management of the urban coastal environment," and one of the outcomes it is working to achieve is the sustainable and integrated planning and management of natural and built coastal and estuarine assets (SCCG 2012*a*). Information is exchanged between councils at regular fora, workshops, through newsletters and reports. The group is also involved in advocacy, making submissions on policy issues relating to planning and climate change adaptation. These include recent submissions to the State Government regarding the *Coastal Protection Amendment Bill 2012* and an anticipated submission to the *NSW Government Planning Review Green Paper*. Partly due to the SCCG's position, regressive reforms contained in the Amendment Bill, such as removal of the need for councils to use state-wide sea level rise projections, have been postponed pending further consultation. The SCCG also carries out many climate adaptation projects in partnership with research institutions, such as its Mapping and Responding to Inundation project with CSIRO (SCCG 2012*b*).

Combining forces is not only cost-effective but also gives greater ability to leverage funding. The SCCG example demonstrates that local government alliances can be effective 'bottom up' mechanisms that allow local governments to increase their collective knowledge and power, and address climate change impacts such as flooding.

[13] Note that not all ROCs have climate change, flooding or catchment management as an objective. Some are more focused on regional economic development or other shared goals.

5.3 Regulation by prescription

Development planning is a key measure for flood prevention. If construction in flood prone areas can be prevented, then the costly damage and social trauma associated with floods can be completely avoided. However, prevention of development in flood prone areas has proved difficult to achieve because floodplain land is attractive for settlement, being highly fertile with easy access to water. Minimising flood impacts through controlling development can be achieved through legislation, construction standards and through planning (the latter will be covered in the following section). Queensland and Victoria, the two states most affected by the 2010-11 floods, will be used as examples of legislative and planning measures currently in place and some of the issues that need to be addressed to enable them to adequately mitigate flood risks.

5.3.1 Inclusion of climate change in state planning legislation

State legislation relating to land-use planning generally does not contain any requirement to take climate change into account. Some states have legislation specific to climate change or coastal management and this can include a requirement for decision makers, including planners, to consider climate change, particularly increased flood risk due to sea level rise. There appears to be less consideration of inland flooding due to changes in rainfall patterns. An exception to this is the Queensland Inland Flood Review which recommends the use of a climate change factor for incorporation into flood studies[14] (State of Queensland 2010). The Queensland Reconstruction Authority includes the factor in its model terms of reference for flood investigations, for state-wide application (QRA 2012*b*: 44). According to a recent review by the Productivity Commission, planning regulations that accommodate climate change adaptation need to facilitate a risk management approach, and incorporate community risk tolerance, rigorous consultation processes and full cost benefit analysis of land use. A key component of the risk management approach is for development approvals to be time-limited or trigger-bound to enable land to be used in the short term until new adaptation approaches are needed (Productivity Commission 2012: 139-143).

5.3.2 Non-mandatory provisions

The Queensland government administers development planning through the *Sustainable Planning Act 2009 (Qld)* (SPA). The Act allows for the development of the *Queensland Planning Provisions*, which set out a standard structure for planning schemes and drafting instructions. These Provisions include standard zones and overlays and assessment criteria. In terms of

[14] The review suggests a climate change factor of 5 per cent per degree of global warming be applied to rainfall depths and that local governments use the following projections in their flood studies, pending update of the Australian Rainfall and Runoff handbook: 2^0C by 2050, 3^0C by 2070, 4^0C by 2100.

flooding, the Provisions include a standard overlay for flood hazard in the 'development constraints' category. However, the use of the overlay in planning schemes is optional, even where flood mapping information is available (QFCI 2012: 106-108).

5.3.3 Mandatory provisions have conditional application

The Queensland SPA enables the development of State Planning Policies, with which local government planning schemes in Queensland are required to comply. Provisions relating to flood risk are made through *State Planning Policy 1/03* (SPP 1/03), administered by the QLD Department of Community Safety (DCS). This policy is the most important state planning instrument for ensuring consideration of flood risk. In practice, there are significant problems with applying *SPP 1/03*. One problem is that *SPP 1/03* cannot be applied to local planning schemes unless they both adopt a 'defined flood event' (identify a historical flood, ideally close to a 1 in 100 year event) and have a flood map. Councils that don't include these in their planning schemes can essentially opt out of applying *SPP 1/03* to their planning schemes (QFCI 2012: 97; 118). In Victoria, the application of the *Victoria Planning Provisions* that relate to flooding (including standard zones and overlays) only apply if flood mapping has been carried out (Comrie 2011: 192-194).

5.3.4 Exemptions to standard provisions

Application of planning legislation and instruments to address flood can be significantly compromised by exemptions. The QLD Floods Commission of Inquiry examined many examples where development is exempt from applying *SPP 1/03*.[15] 'Development commitment' such as 'material change of use that is code assessable' and development where there is overriding need in the public interest are exempt. Mining and agricultural activities are not assessable development under the SPA. Activities involving hazardous materials are governed by the *Environment Protection Act 1994 (QLD)* and are assessed according to 'standard criteria' which make no specific reference to flooding (*SPP 1/03* only comes into play when hazardous materials are manufactured or stored 'in bulk'). Placement of fill on floodplains to raise soil level to build on can be exempt under certain circumstances, as is placement of fill for infrastructure construction by authorised public sector entities. Some aspects of the electricity supply network are 'exempt development' and in some planning schemes minor levees can be exempt.

Some types of community infrastructure (unless identified in the *SPP 1/0*3 list) are 'exempt development'. Community infrastructure not covered by *SPP 1/03* includes childcare, aged care, schools and electricity works, among others. *SPP 1/03* requires community infrastructure to

[15] QFCI 2012. Exemptions referred to in this section are found on pp 91, 98, 108, 149, 153, 156, 166, 169, 175, 190-193, 197, 242-244.

function effectively during and after a flood of a specified flood risk level. This is generally set between the 1:200 year and 1:500 year event flood level. However, for categories of community infrastructure not included the *SPP 1/03* definition, these standards do not apply.

As an illustration of problems with exempt community infrastructure development, the Inquiry offers the case of a Goodna childcare facility. Catering for 115 children, it was built on a site that was flooded in 1974, adjacent to an overland flow path and near the 1 in 20 year event flood line. The centre was inundated to a depth of 1.8m and had to be evacuated for 45 days. A Yeronga aged care facility was similarly affected. Built in a waterway corridor, evacuation routes were submerged and the site was submerged to a depth of 1 metre. Some residents were unable to return for two months (QFCI 2012: 150, 174, 201).

Most development in Queensland is administered through the *Sustainable Planning Act 2009 (Qld)*. However, there are some other planning systems that operate under different legislation. These satellite planning schemes provide for development such as affordable housing (the aim being to expedite approval of development applications); legislation governing the development of a specified riverside area of Brisbane; state development areas (which can include developments such as hospitals, infrastructure and essential services); and significant projects (including high value mining projects). As satellite planning systems are not subject to the SPA, they are not required to comply with *SPP 1/03* (QFCI 2012: 138-143).

5.3.4 The Federal Government Role

Under constitutional arrangements, the Federal Government has little ability to legislate on planning issues but it has adopted a leadership and coordination role through intergovernmental agreements.

Overseas experience suggests it could be possible for the Australian Federal Government to expand its influence should it wish to do so. The USA, a country where federal government involvement in land management is similarly restricted, has implemented legislative measures that encourage improved land use and development controls. The USA's *Flood Disaster Protection Act 1973* prohibits federal agencies from providing communities with assistance in floodplain acquisition or construction unless communities participate in the National Flood Insurance Program. This program (as well as requiring mandatory insurance), imposes minimum land use and control requirements for new construction in flood prone areas. The Act's provisions also apply to "financial institutions regulated or insured by the federal government, thereby covering virtually all types of financial assistance" (Wright 2000: 34-35). While national flood insurance is unlikely to be an approach suitable for Australia[16], it demonstrates that there are possibilities for the Federal Government to apply legislative incentives to reduce future disaster relief and recovery bills.

The Federal Government has itself been at fault in not applying adequate flood controls. The SIRP report provides examples of development of flood prone areas that were funded through the Commonwealth government's economic stimulus package. At a minimum, the Commonwealth needs to ensure its own development projects are subject to adequate assessment and controls.

5.3.5 Building codes and standards

While it is preferable to avoid siting development in areas of flood risk, this is not always possible to achieve (QFCI 2012: 223, 245). Improved materials and design can be used to improve flood resilience and can significantly reduce damages and enable rapid clean up and recovery. This is a useful adaptation measure for climate change, as it can mitigate more frequent small flooding as well as extreme flood events. Prescriptive building requirements are generally easier to apply to new development, but they can also be applied to rebuilds, as in the case of North Wagga (Wagga Wagga City Council 2010).

National building standards are set through the *Building Code of Australia*. These are minimum standards only and states may enact more rigorous standards. Currently there are no national standards for building in flood-prone areas, though the Australian Building Codes Board is in the process of developing a standard for residential development (Comrie 2011: 193; QFCI 2012: 212).

The draft *Standard for Construction of Buildings in Flood Hazard Areas* contains the following definitions:

> ***Defined flood event (DFE)***: the flood event selected for the management of flood hazard for the location of specific development as determined by the *authority having jurisdiction*.
>
> ***Defined flood level (DFL)*****:** the flood level associated with a *defined flood event (DFE)* relative to a specified datum. The DFL plus the *freeboard* determines the extent of the *flood hazard area*.
>
> ***Flood hazard level (FHL)*****:** the flood level used to determine the height of floors in a building and represents the *defined flood level (DFL)* plus the *freeboard*.
>
> ***Freeboard*****:** the height above the *defined flood level (DFL)* as determined by the *authority having jurisdiction*, typically used to compensate for effects such as wave action and localised hydraulic behaviour.

[16] Wright (2000) notes that in the USA, flood insurance represents the largest potential demand on the Federal Treasury after social security (p.41).

(ABCB 2012*b*:11-12)

These definitions are based on historic flood levels and do not incorporate possible future flooding scenarios due to climate change or land use change. Indeed, the draft standard makes no reference to climate change.

The Australian Building Codes Board has also produced a draft *Information Handbook* to accompany the Standard. Reference to climate change is contained in the Handbook's background. It explains its effect on flooding, flood water velocity, depth, and the need to consider this when selecting a Floor Height Level. However, the purpose of the document is only advisory: "this Handbook is not mandatory or regulatory in nature. Rather, it is designed to accompany the ABCB Standard for Construction of Buildings in Flood Hazard Areas and to assist in making information on this topic readily available" (ABCB 2012*c*: ii, 3). If the Handbook does no more than provide information it is questionable whether it will have much influence on ensuring climate change is incorporated into key local planning tools. This is disappointing given the rhetoric surrounding the need to improve building codes.

Building construction in Victoria is regulated by the *Building Act 1993 (Vic)* and *Building Regulations 2006 (Vic)*, of which one, regulation 802, relates to flood. However, the only design aspect that can be specified through this regulation is floor height. The regulation does not include flood resilient materials or other design features (Comrie 2011: 193). Some Victorian legislation specifically relates to controlling increased urban run-off due to subdivision. It is thus an important instrument for controlling aspects such as amount and velocity of stormwater, aspects that have a big impact on infrastructure. These provisions are contained in Clause 56.07-4 of the *Victoria Planning Provisions*, which were amended in 2006. There have been issues regarding compliance with the Clause 56 and it is currently being reviewed (Hussey, pers. comm.).

Queensland's state building standards are regulated by the *Queensland Development Code* and *Building Regulation 2006 (Qld)*. The Code does not include regulation of building construction in areas at risk of flooding. The government is drafting a new mandatory part to the code, Part 3.5 'Construction of Buildings in Flood Hazard Areas', based on the new draft national standard. This would cover design, but not water resistant materials. The latter may form a non-mandatory provision (QFCI 2012: 211-213).

As per development planning legislation, building codes only apply if flood hazard areas have been designated, although Victoria has better provisions than Queensland in that the local planning scheme is not the only mechanism by which flood-prone land can be identified (Comrie 2011: 193, 196; QFCI 2012: 213).

5.3.6 Catchment management authorities and the development approval process

The Comrie Review investigated development approval processes in Victoria. Under the *Planning and Environment Act 1987 (Vic)*, planning permits in that State have to be referred to the relevant Catchment Management Authority (CMA) if the land is in a flood zone or overlay (flood information and mapping is thus a prerequisite to mandatory referral, though advice may also be sought without it). CMAs have the power to refuse development or impose conditions on development to make it more flood resistant. The assignment of this role to CMAs is appropriate as they have technical expertise in flood management and a long term understanding of flood risk implications. Their value in providing a long term perspective is particularly relevant to adapting to future flood scenarios. The review also points out that, unlike councils, CMAs are not subject to competing pressures from interest groups and short term economic gains such as rates increases.

Current state policy in Victoria aims to remove this power from CMAs, not only removing their power to refuse development, but also removing their ability to impose conditions. Any advice they provide will become non-binding. The review finds this will 'inevitably lead to poor flood planning outcomes' and recommends that CMAs retain their powers (Comrie 2011: 192, 197). The Victorian Government is not planning to make a formal response to the report, however of the 93 recommendations, three have not been accepted. One of those not accepted was the recommendation that CMAs retain their current powers. This has been confirmed by the Victorian Minister for Police and Emergency Services (Ryan 2012) and is also alluded to in Victoria's ENRC Inquiry (Parliament of Victoria 2012: 21-22).

5.3.7 Conclusion

Development planning was identified in the SIRP report as being one of the most important adaptation measures to address climate change flooding. However, evidence from recent flood inquiry reports suggests that provisions in some states are inadequate to accommodate even existing risks of flood. The flood reviews reveal numerous issues with planning and development legislation in Australia which result in ad hoc consideration of flood risk and implementation of mitigation measures. Much of the lack in consistency in the way legislation deals with flood risk is likely to reflect conflicting policy objectives, as discussed in the intra-governmental section above. Many of the legislative exemptions appear to increase the vulnerability of groups that are already vulnerable and compromise the resilience of essential infrastructure.

While state legislation and instruments already exist, they need to be amended to ensure more consistent consideration of flood in the development process. The application of legislation can also be improved through ensuring adequate flood information, improved administrative processes and clear and appropriate responsibilities and accountabilities.

The use of Catchment Management Authorities in the development approval process provides one of Australia's best models for ensuring a more comprehensive approach to development planning, incorporating flood risks and extending beyond narrow administrative and temporal boundaries. It is of concern that this is currently under threat. These issues compromise adaptation to flooding, regardless of any increase in risk that comes with climate change.

5.4 Planning processes

5.4.1 The adequacy of planning tools to accommodate climate change

Adoption of a Defined Flood Event (DFE) or Flood Level is a key planning tool in both Queensland and Victoria. According to the Queensland Inquiry, state planning instrument *SPP 1/03* which addresses flood risk cannot be applied unless planning schemes adopt a DFE. Generally a 1:100 year event is selected, with an additional freeboard of between 300 and 500 millimetres (Comrie 2011: 193; QFCI 2012: 63, 147). The 1:100 year level is not a compulsory requirement in Queensland but is included in Victoria's *Water Act 1989 (VIC)* as a minimum default that applies to Catchment Management Authorities. The defined flood event is based on an historic flood and it is used to determine the level of flood hazard for a location and any development controls that need to be applied to mitigate risk. For example, it can be used to prevent incompatible development from being sited in an area of flood risk or it can apply controls such as the height of habitable floor levels.

Analysis in the SIRP report found significant barriers to incorporating up-dated information into planning schemes in both Victoria and Queensland, including a ten-year interval before some planning instruments become due for revision, the complexity of approval processes, cost, compensation liabilities and competing pressures. These can all prevent timely incorporation of flood data, including climate change information, into planning schemes. According to a recent report by the Productivity Commission, climate change risks are not consistently managed in land-use planning schemes, with local governments hampered by a lack of guidance from state governments and financial and expertise constraints (Productivity Commission 2012: 151).

Recent studies suggest that the use of the 1:100 year event standard for flood control may be inadequate, particularly in countries with a short term flood records like Australia. As flood frequency is calculated on past flood events, any subsequent severe flood adds to data and can lead to recalculations. Inaccuracies can also occur as a result of out of date techniques and assumptions. Whether due to inaccurate data, climate change or urbanisation, the 1:100 flood line is not static but can move. This can place people at unacceptable risk of flooding (Wenger *et al*. 2012).

Studies in the US indicate that twenty per cent of repetitive flood losses occur outside the designated 100-year floodplain, suggesting the accuracy of flood mapping is a significant problem (NWF 1998: 58). In Australia there are also indications that the 1:100 year event can be inaccurate.

Uncertainties regarding Brisbane's 1:100 year flood line were identified in the QFCI, with past estimates ranging from 3.16 m to 5.34 m at the city gauge (QFCI 2011: 20, 38; QFCI 2012: 48-51). In another example, a 2004 flood study of Wagga Wagga determined that the 1974 flood in that city, which had previously been considered a 1:90 year event, was actually a 1:60 year event (Askew 2009).

Data accuracy, assumptions and collection techniques aside, future changes such as development and climate change are expected to alter catchment hydrological conditions; what was once a 1:100 year event may become a more frequent occurrence. A study by Melbourne Water on the impacts of climate change on flooding found that rainfall intensity over five urban catchments in Melbourne was likely to increase and that the interval between large scale events would decrease. Using existing tools and models, they found a 30% increase in rainfall intensities was likely by 2030, at which point there would be a period of pseudo-stationarity till 2070.

> While results varied from catchment to catchment typical results from this analysis indicated the 2070 1 in 5 year design ARI event was equivalent to the present 1 in 10 year ARI event and the 2070 1 in 100 year ARI event was equivalent to the 1 in 300 year ARI event.
>
> (Pedruco and Watkinson 2010: 1)

The impact of development on flood frequency has also been studied. In a US example, development caused a seven-year event to become an annual one, and what was once a 1:100 year event now occurs 1 in every 25 years (Freitag *et al*. 2009: 44-45).

Overseas reviews suggest that planning tools based on the 1:100 year event are inadequate to deal with existing and future threats. The USA, which pioneered the use of the 1:100 year standard to administer its National Flood Insurance Program, has been debating a move to the 1:500 year event. This is more in line with safety standards for other hazards and is particularly suitable for urban areas where rapid evacuation is harder to achieve. While the 1:500 year flood event is just as arbitrary as the 1:100 year standard, it provides a greater margin of error of use for adapting to future uncertainties such as climate change and continuing development (Wenger *et al*. 2012).

Flood risk is not only determined by flood area, but also by velocity and depth. A blanket standard should not be selected simply because it is administratively easy to apply. A 1:100 year flood may be relatively shallow and the difference between it and a 1:500 year flood only a matter of centimetres. If the terrain is flat, a flood may be weeks in coming, giving ample warning time to move valuables and prepare. In steeper, more confined catchments, a 1:100 event may be deep and occur with little warning. According to the Bureau of Transport and Regional Economics, the difference between a 100-year flood level and the probable maximum flood can be measured in centimetres for most NSW floodplains (BTRE 2002). Thus, adapting to higher flood frequencies may only require minimal adjustments - for example, of floor height requirements - in many areas of Australia.

Recent Australian flood reviews reinforce a need to move away from a single defined flood level for development planning. The Brisbane Flood Review endorses a Flood Taskforce recommendation that flooding up to the most extreme event should be considered. It supports a risk management approach in line with the National Flood Risk Advisory Group (NFRAG) guidelines (Arnison *et al*. 2011: 57). The QFCI similarly finds the focus on a single defined flood event is insufficient:

> Restricting development within the extent of the [1:100 year] flood will manage a portion of the risk, but it does not deal with the risk of floods that are less frequent, but more severe, or those that will occur more often, but with less damaging consequences. Instead, the various areas to which planning controls apply should be selected having regard to the likelihood, behaviour and consequences of the full range of possible floods, up to and including the probable maximum flood.
>
> (QFCI 2012: 63)

However, it is concerning that neither the QFCI, the Comrie, nor the Brisbane flood reviews discuss the fact that weather patterns under climate change are unlikely to remain stationary, and that likelihood values may change. A particularly notable omission is in the QFCI discussion on flood mapping, even though the issue is well-recognised by water resource management professionals.

The QFCI found that residential housing needed to be located in low hazard areas as this use was most vulnerable to flood in terms of loss of life, injury and property damage. However, at one point, the QLD Inquiry contemplates accepting lower habitable floor levels for residential areas, for example, at the 1:50 year flood level, depending on the community's willingness to accept risk (QFCI 2012: 147-148). The question of who bears the cost of that risk, be it the communities themselves, insurance companies, charities, taxpayers or future generations, is not discussed by the Inquiry. A recent decision by Suncorp to not insure entire towns for flood risk unless mitigation measures are undertaken indicates that insurance companies, at least, are not willing to bear that cost (Jabour 2012). Accepting lower floor levels seems maladaptive if lesser floods are expected to increase in frequency and if the number of large floods is expected to increase.

Despite the lack of integration of this issue into its report, the QFCI does include reference to climate change in some instances. Its expert panel recommended that climate change risks be included in a new Brisbane flood study. The Inquiry also received evidence from North Burnett Regional Council about a commissioned flood study aiming to incorporate climate change into its flood risk management framework and into its DFE (QFCI 2012: 45, 130). Based on the North Burnett study, a climate change factor that addresses inland flooding is expected to be applied state-wide (QRA 2012*b*: 45).

A current review of *SPP 1/03* is considering when it is appropriate to select a greater or less than 1:100 year flood as DFE. Matters that are being considered in the review include resilience to flooding in a changing climate. In this context, the review will be looking at whether there needs to be standardisation for determining a defined flood event and undertaking flood studies; when it is appropriate to use a defined flood event greater or less than the 1:100 year flood event standard for residential development; and how to improve the integration of land use planning and disaster management (QFCI 2012: 99). Thus there is potential for planning instruments dealing with flooding to be strengthened in line with current understanding of threats. However, the many issues surrounding the application of *SPP 1/03* (as discussed in 'intra-governmental function' and 'regulation by prescription' sections) would also need to be addressed for it to be effective.

5.4.2 Ecosystem approaches to flood management

The SIRP report identified floodwater velocity, or energy as a significant aspect of flooding which had little coverage in most reviews (though it was covered by Victoria's ENRC Inquiry). Velocity causes some of the most expensive damage, primarily to infrastructure such as roads, bridges and railways, but also in terms of erosion and loss of farmland, reduced water quality and long term reductions in storage capacity of dams due to siltation.

Improved land management can reduce these problems. In countries such as the Netherlands, China and the USA, 'Room for the River'[17] initiatives allow more land to flood through wetland restoration, relocation, levee removal or setback and flood-compatible land use. By giving water more room to spread, floods are shallower and water velocity is reduced. Often these changes are associated with multiple economic, social, environmental and health benefits. They rely

[17] This strategy was developed by the Dutch as part of their Delta program following dangerously high water levels in 1993 and 1995

strongly on integrated catchment management approaches that seek optimal outcomes across sectors and communities. Case studies for these countries are provided in the SIRP report.

Australian researchers interviewed for the SIRP report suggest that work needs to be done primarily in the upper catchment to impede water. Thus, rather than clearing and straightening water channels, vegetation actually needs to be encouraged to grow inside them and for water to spill over onto the floodplain. This is a completely revolutionary idea that strongly contrasts with current practices and community views (Parliament of Victoria 2012: 114-118; Wenger *et al*. 2013). Upper catchments would be encouraged to flood and hold water temporarily in wetlands or detention basins and then gradually release it back into the system.

This approach has many benefits besides reducing damages. It would delay flooding downstream, and thus increase warning times and potentially reduce damages and casualties from flash flooding. It would also reduce flood peaks, and crucially, decrease the power of floodwaters in the middle and lower catchments. Another benefit is that it could allow aquifer recharge, a significant benefit that could help address increasing severity of climate change drought. By contrast, channel straightening, vegetation removal and floodplain levees to protect rural land can be counter-productive in that they increase velocity and transfer flood problems downstream or across to neighbouring properties.

As the most productive farmland tends to be located in the middle catchments, little can be done there to reduce the power of the flow. Suitable interventions in middle catchments could include bank stabilisation with riparian vegetation. By contrast, land in upper catchments is generally of lower value and there is scope to ensure compatible dryland grazing uses.

A business case that applies ecosystem approaches to sediment reduction in the Moreton Bay area was recently prepared by the Queensland Conservation Council in collaboration with university researchers as part of the Healthy Waterways Partnership. It found that 70% of the sediment is coming from 30% of the region, suggesting that it is possible to target activities to specific localities. This example also suggests that in the Australian context, ecosystem approaches would be cost effective in terms of water quality and supply, as well as having side benefits for fisheries and wildlife. The value of avoided flood damage costs was not included in this study (QCC 2012).

Ecosystem approaches to flood mitigation are probably the least understood in Australia. Interviews conducted for the SIRP report found that, other than researchers and floodplain managers trained in natural resource management, flood professionals had only limited understanding about ecosystem approaches and many reservations. A reason for lack of understanding about this approach could be the segregation between traditional flood management and natural resource management disciplines. However, ecosystem approaches are widely used overseas as a strategy to adapt to climate change related flooding. They can mitigate the impacts of flooding for existing as well as future development, and thus have a wider reach than development planning.

A further barrier for this approach is lack of community understanding about hydrology. Following the recent floods misperceptions about the causes of flooding resulted in significant activity clearing vegetation and debris from water channels. Such activities increase the efficiency of waterways, resulting in greater water velocity and flood impacts downstream. They are thus maladaptive. Modelling reported in the ENRC Inquiry found that vegetation had a minimal effect on local flooding. For example, at Creswick, clearance would have reduced the water level by 15cm without changing the number of houses that were flooded (Parliament of Victoria 2012: 113).

5.4.3 Achieving an ecosystems approach

One of the biggest challenges for implementing an ecosystem approach is that it requires flood studies, modelling, risk assessment, planning and implementation on a catchment scale, rather than on the individual town or locality scale, which is currently the norm. Local council responsibilities stop at their municipal boundaries and achieving a catchment approach to flood management is beyond the financial and skills capacity of most councils. Implementing catchment approaches needs to be led from a state level and must involve all players.

States vary widely in the administrative structures they have in place for whole of catchment management. Victoria has a great advantage in this regard as its historic Public Purpose Reserve system means that 25,000km of riparian land is owned by the Crown rather than privately owned. This greatly facilitates riparian management. Victoria has enacted a catchment approach through its *Catchment and Land Protection Act 1994 (Vic)* and *Water Act 1989 (Vic)*, which together establish ten Catchment Management Authorities and provide them with specific responsibilities and powers, along with resourcing direct through the State Government. These arrangements overcome the limitations of artificial administrative boundaries. CMAs involve local stakeholders through Floodplain Management Advisory Committees. Their roles include overseeing floodplain management strategies, involvement in planning schemes, flood warning support, conservation of natural assets, managing flood infrastructure and provision of monitoring and advice (Parliament of Victoria 2012: 20-22). They currently have a strong role in the development approval process as 'designated referral authorities for local government in implementing statutory planning provisions and for proposed construction of infrastructure assets on floodplains' under the *Planning and Environment Act 1987* and the *Water Act 1989*.

CMAs would appear to be well placed to implement ecosystem approaches to flood control, and indeed have been doing so for many years through their management of riparian vegetation. However they would need adequate resourcing if they were to undertake programs of similar scope and complexity to those overseas.

By contrast, Queensland's 14 catchment organisations are not public entities. Some are community based, not-for-profit organisations that rely on a variety of government and non-government sources for funding, such as South East Queensland Catchments Inc. and Desert Channels Queensland Inc. Others, such as Reef Catchments Ltd operate on a business model and generate income through consultancies as well as accepting government grants. While they are 'regional' organisations they are structured around catchments (for example, South East Queensland Catchments encompasses 14 catchments). The websites of many of these bodies state that they were first established using federal funding, rather than by the State Government. For example, the Burnett Mary Regional Group for Natural Resource Management Ltd (BMRG) states that it was formed under the National Action Plan for Salinity and Water Quality and the Natural Heritage Trust programs (BMRG 2012). A scan of the these organisations' activities indicates that many of them are involved in climate change adaptation, for example, Desert Channels Queensland organised a Climate Change Adaptation Forum through its Landholder Support Service Project (DCQ 2012).

A crucial difference between the Victorian system and the Queensland system is that in Victoria, catchment based management has been embedded in legislation, with defined roles, responsibilities and powers, while Queensland's NRM bodies are only in the position to facilitate improved land management.

When a catchment approach is enforced in Queensland, it requires intervention at state level. Recently the Queensland State Government implemented a Reef Protection Package "ReefWise Farming" aiming to protect the Great Barrier Reef and sea grass beds. Part of the rationale for the program is that climate change is expected to result in larger floods and longer droughts, leading to increased erosion and nutrient run-off. The package includes a new planning instrument that regulates land use, *State Planning Policy 4/11: Protecting Wetlands of High Ecological Significance in Great Barrier Reef Catchments*, which came into effect in November 2011. It is designed to regulate earthworks by maintaining a buffer of 50-200m around wetlands in the Great Barrier Reef catchments. Protection does not extend to river channels, however, and the connectivity between rivers and wetlands is not addressed (QLD Government 2011).

There are examples of robust catchment management mechanisms in Australia that are well placed to implement ecosystem approaches to flood management. However, catchment mechanisms in Queensland, the State most prone to severe flooding, lack authority and State Government backing is confined to special instances. More needs to be done to enable a consistent whole of catchment approach to planning and land management in all states and territories of Australia. This would not only help to mitigate flooding but could lead to other benefits such as improved water quality, protection of natural assets, farmland and fisheries, resilience to drought, and enhancements for tourism, amenity and recreation.

5.5 Funding Function

5.5.1 National Partnership Agreement on Natural Disaster Resilience

The *Natural Disaster Resilience Grants Scheme*, administered under the *National Partnership Agreement on Natural Disaster Resilience*, is the primary funding mechanism that supports disaster prevention in Australia. While the Agreement pre-dates the *National Strategy for Disaster Resilience*, it is viewed as being a funding mechanism that supports it (AGD 2011: 122-123). The amount allocated by the Federal Government to this agreement is approximately $100 million over four years (2009-10 to 2012-13), to be divided between all the states and territories (COAG 2009). Under the terms of the agreement, recipients are required to match Commonwealth funding and state/territory annual implementation plans indicate that matching funds are also commonly required from local government or other agency beneficiaries, thus providing leverage opportunities (e.g. see NSW Implementation Plan 2010/11). A survey of NSW projects approved since 2009 indicates that funding was awarded to local councils, state government agencies and organisations responsible for emergency response. Project descriptions are not detailed enough to assess whether climate change adaptation is incorporated. However, a number of grants were awarded to the NSW Department of Environment, Climate Change and Water (NSW Government 2012).

The Federal Government allocates an additional $3.6 million towards natural disaster resilience each year through *National Emergency Management Projects*, approved directly by the federal Minister of Emergency Management (AGD, nd). Combined, these funding mechanisms provide approximately $28.7 million per annum of federal money to natural disaster resilience.

The *Natural Disaster Resilience Program* replaces the earlier *Natural Disaster Mitigation Program* which paid $24.5 million per year in grants (average calculated as from July 2007, when the *Regional Flood Mitigation Program* was incorporated into it); the *Bushfire Mitigation Program* (an average of $4.8 million per year) and the *National Emergency Volunteer Support Fund* (average of $3.5 million per year). The total amount is roughly the same as provided by current funding programs.

The *National Partnership Agreement* is extremely broad. The agreement objective is stated as being "Australian Communities that are resilient to natural disasters". Funding is divided between all states and territories, and between all natural hazards. The Agreement defines resilience as “the capacity to prevent/mitigate, prepare for, respond to and recover from the impacts of disasters”. Thus the funding may also be divided between all phases of PPRR. A survey of annual implementation plans indicates that the emphasis is on prevention, preparation and response (in the form of support for emergency volunteers), though some plans explicitly include recovery as well (e.g. the South Australian Implementation Plan for 2010/11). A disadvantage of this breadth of coverage is that limited funds are thinly spread. The paucity of the budget was illustrated by an interviewee of the SIRP report, who commented that the entire annual budget was barely sufficient to construct a flood levee for a single country town (Wenger *et al*. 2013).

Australia’s average annual disaster damage bill, not incorporating recent flood costs, is approximately $1.233 billion. Flood damages make up the largest proportion of this amount, averaging $377 million per year (BITRE 2008).[18] The cost effectiveness of investment in disaster mitigation is well recognised. A report to COAG on disaster mitigation reform noted, “recent analysis shows that over some 67 projects, every dollar invested in flood mitigation saved more than $2.10” (DOTARS 2004: 24). Some USA sources suggest the benefit of investing in mitigation is considerably higher (Wenger *et al*. 2013). In this context, the annual allocation of $30 million by the Federal Government towards disaster resilience appears grossly insufficient.

The Partnership Agreement cover page describes the Agreement as “mitigation” and this is also how it is promoted on Attorney-General Department webpages and annual reports. However, the Partnership Agreement definition of mitigation, "measures taken in advance of, or *after*, a disaster aimed at decreasing or eliminating the impact of disaster on society and the environment,"[19] is at odds with standard definitions found elsewhere. Most definitions state that mitigation involves activities that are undertaken before a flood, while response is primarily *during* a flood and recovery *after* (EMA 1998: 76, 88, 92, 94; Parliament of Victoria 2012: 26). While the agreement is commonly described as the Commonwealth’s contribution to mitigation funding, deviation from the standard definition of ‘mitigation’ is misleading and compromises

[18] Figures are given in 2005 prices for the period 1967-2005, and do not include recent floods (p.44).

[19] My italics. Quoted from Schedule A of the National Partnership Agreement on Natural Disaster Resilience. According to the Emergency Management Manual Series’ *Australian Emergency Management Glossary*, mitigation is defined as “Measures taken in advance of a disaster aimed at decreasing or eliminating its impact on society and environment”. The partnership agreement definition has added the words ‘or after’ to this standard definition. *Emergency Management in Australia Concepts and Principles* (2004), in the same series, expressly separates ‘prevention/mitigation activities’ from preparedness, response and recovery activities. Activities such as relocation or rebuilding to a higher standard that are carried out *following* a flood are mitigation, but such activities are undertaken in anticipation of (i.e., before) the next disaster.

this description. Moreover, lack of detail provided by most states about projects funded under the agreement makes analysis of the relative proportion of funding allocated to prevention (and to floods as opposed to other types of hazard) difficult.

The Partnership Agreement is touted as addressing climate change adaptation on websites and in annual reports[20]. The Attorney-General's website states, "A key aim of the NPA is to enhance Australia's resilience to natural disasters through mitigation works, measures and related activities that contribute to safer, sustainable communities better able to withstand the effects of disasters, particularly those arising from the impact of climate change." However, the Partnership Agreement itself makes no mention of climate change. Wording relating to climate change is included in some of the Agreement's state/territory annual implementation plans. Generally this is in the form of acknowledgement of climate change rather than specific strategies to address it. A study of the eight implementation plans for 2011-12 found that six made no reference to climate change, one included climate change in its preamble[21] and the remaining one included climate change in its performance measures[22]. The fact that climate change rates little mention does not mean that it has been neglected in the implementation of the Partnership Agreement, as the implementation plans are not particularly detailed. However, it makes it hard to gauge the level to which it is integrated. All of the state/territory plans for 2009/10 include natural disaster risk assessment (this being a partnership agreement requirement for determining implementation priorities). Climate change is likely to have been considered when undertaking these risk assessments.

5.5.2 Climate Change Adaptation Program

The federal Department of Climate Change and Energy Efficiency funds a number of climate change adaptation initiatives through its Climate Change Adaptation Program. In recent years this has included grants schemes such as the Local Adaptation Pathways Program (LAPP) and its Integrated Assessment of Human Settlements sub-program. LAPP (which operated from 2008-2010) provided around $2 million to local governments to carry out climate change risk assessments and adaptation action plans. At least some of these projects considered flood

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[20] For example, the Attorney-General's Department Annual Report 2009/10, p.102; the Attorney-General's Department website http://www.em.gov.au/npa (accessed 22.10.12).

[21] "Climate change is expected to further increase natural disaster risk particularly in the coastal zone" in New South Wales Implementation Plan – 2011-12
http://www.federalfinancialrelations.gov.au/content/npa/environment/natural_disaster_resilience/NSW_1112.pdf (accessed 30.10.12)

[22] "proportion of projects that consider possible climate change impacts" in Australian Capital Territory Implementation Plan – 2011-12.
http://www.federalfinancialrelations.gov.au/content/npa/environment/natural_disaster_resilience/ACT_11-12.pdf (accessed 30.10.12)

risk[23]. A related funding scheme, the Coastal Adaptation Decision Pathways Program, received applause from the Queensland Government in a recent submission to the Productivity Commission (Queensland Government 2012*b*). The Climate Change Adaptation Program also funds national vulnerability assessments, including the National Coastal Risk Assessment that investigated threats of coastal flooding due to rising sea levels.

5.5.3 Natural Disaster Relief and Recovery Arrangements

Disaster recovery is primarily funded through the *Natural Disaster Relief and Recovery Arrangements* (NDRRA) grants process. This is activated if financial thresholds for disaster costs are exceeded. When this is the case, the Commonwealth Government will share disaster costs with state governments. The proportion of assistance depends on the amount of damages. For the Victoria 2010-11 floods, the Commonwealth's share became 75% when the cost of replacement in "Category B" (including replacement of essential public assets) reached $155 million (Comrie 2011: 207).

According to the Attorney-General's Department Annual Report for 2010-11, the cost of public infrastructure reconstruction following the 2010-11 floods was estimated to be around $6.6 billion, (representing three quarters of the total expense funded through the NDRRA, the balance to be funded by state governments). In addition to this, $823 million was provided to individuals through the *Australian Government Disaster Recovery Payment*, and a further $73 million in *Disaster Income Recovery Subsidy* (AGD 2011: 122). For a country with a relatively small population, this is a significant cost.

In order to fund this enormous recovery bill, the Commonwealth government implemented an additional tax levy on Australian income earners (not applicable to anyone living in a flood affected area or to low income earners). It also reduced or discontinued spending to numerous Commonwealth government programs. The vast majority of these programs were 'Clean Energy' programs: the Cleaner Car Rebate Scheme, the Green Car Innovation Fund, the Carbon Capture and Storage Flagships program, the Solar Flagships program, the Renewable Energy Bonus Scheme, the Green Start Program, the Solar Homes and Communities Plan, the Global Carbon Capture and Storage Institute. Other programs that were cancelled or reduced included the National Rental Affordability Scheme, the Australian Learning and Teaching Fund, the LPG Vehicle Scheme and a number of regional and local infrastructure programs (Gillard 2011*b*). It can be concluded from this that Australians, both individually via increased tax and as a nation,

[23] For example, see the "Climate change in Western Port, Victoria: An integrated assessment of impacts on regional settlements and adaptation response" project, http://www.climatechange.gov.au/government/initiatives/climate-change-adaptation-program/lapp-ia.aspx (accessed 30.10.12).

have sacrificed much to subsidise the flood relief effort. It is also ironic that many of the programs sacrificed are the ones designed to mitigate climate change, a phenomenon likely to increase our exposure to flooding.

While recovery is generally not viewed as being 'prevention', it can become so. The SIRP report compared disaster relief policies and funding in Australia with those of the United States. In 1993, floods in the upper Mississippi caused a major shift in disaster relief and there was a "consensus that rebuilding or restoring to pre-flood conditions was not an acceptable policy position" (Wright 2000: 173). During the 1990s, recovery and mitigation became increasingly integrated in the United States and for some disasters they completely merged. Recovery funding took the form of purchase of damaged or destroyed property; rebuilding away from flood hazards; and reducing exposure of rebuilds through measures such as elevation of structures. With the *Hazard Mitigation and Relocation Assistance Act (1993)*, mitigation funding increased, and 15% of all federal disaster costs were required to be spent on mitigation. In some cases this meant whole communities could be relocated (Wright 2000: 69, 78-79). Analyses of avoided flood damages indicate that US investment in preventative measures following a flood, such as relocation, have saved considerable amounts of money. In the upper Mississippi, the 1993 flood caused $20 billion in damages. Following this, $150 million was spent on relocation. In 2008, a similar-sized flood occurred in the same area but as a consequence of preventative measures undertaken as part of the earlier recovery efforts, the later flood had a much lower damages bill of $2 billion (Freitag *et al*. 2009: 5-6; NWF 1998: 60-61).

Australia has yet to realise the financial benefits of integrating disaster prevention into recovery funding. Attempts have been made to incorporate 'betterment' into recovery funding but these efforts have so far failed. While 'betterment', or rebuilding to improved standards, is technically allowed by the NDRRA, at the time of writing, Comrie reported that no betterment projects had ever yet been approved by the Commonwealth (Comrie 2011: 210-211). Since his report was published, one betterment project has been approved, in Tumut Shire NSW, to relocate a public pool that had suffered repetitive damage (AGD, pers. comm.)[24]

There are many difficulties in achieving betterment. The most significant impediment is that when infrastructure is damaged, it needs to be rebuilt as soon as possible, and yet betterment applications, involving both an application and cost benefit analysis, take time to prepare and approve. Early attempts in the United States to integrate mitigation into recovery were similarly limited due to the speed with which recovery measures need to be implemented following a disaster and the time required to assess options (Wright 2000: 78). Other issues implementing

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[24] National Disaster Recovery Programs Branch, Emergency Management Australia, Attorney-General's Department

betterment were also presented during SIRP interviews. One related to identifying potential problems in advance. If infrastructure is identified as being a potential candidate for betterment prior to a disaster, duty of care requires it to be included in a schedule of works. Once it is part of a normal works program, it may no longer be eligible for betterment. This suggests that an agreed process is needed that enables identification of infrastructure subject to betterment prior to a disaster and pre-approval of a resilient rebuild standard. However, it would be important to design the process to ensure it did not encourage construction of sub-standard infrastructure in the hope that a major disaster would result in a free upgrade.

Disaster relief and recovery funding can have another effect on disaster prevention, and that is the perverse effect of removing the incentive to invest in prevention. Interviews with different stakeholder groups undertaken as part of the SIRP report found widespread dissatisfaction over the lack of mitigation and betterment funding and of overgenerous disaster relief and recovery funding. Interviewees felt that the billions spent on repairing infrastructure would not increase resilience but would be incurred again after the next large flood event. Many were highly concerned that the Commonwealth, by investing so much in recovery funding, was also creating disincentives for states and local governments to apply adequate preventative measures, such as improved development planning. Disapproval was also expressed about the untargeted nature of individual payments that did little to help those most severely affected and that could have been used to assist rebuilds. Individual cash payments have been similarly criticised in America. Another significant concern was the lack of balance between federal disaster mitigation funding and relief and recovery funding, with some interviewees noting the relative cost effectiveness of spending on mitigation, in terms of reducing response and recovery costs (Wenger *et al*. 2013).

The SIRP Report study of disaster relief in the US found that generous federal disaster subsidies can increase state and local government dependency and reduce the imperative for them to invest in disaster prevention and preparedness. While accepting the benefits of occupying floodplains, the costs of occupying that land are externalised to federal governments and taxpayers. Similar to Australia, state and local governments are responsible for land use in the United States and the implementation of development controls is widely held to be the most effective flood prevention tool. There is a fundamental disconnect if those responsible for implementing development controls are different to those who pay for the consequences of failing to implement them (Wenger *et al*. 2013).

The COAG National Strategy for Disaster Resilience lists as a priority outcome:

> Following a disaster, the appropriateness of rebuilding in the same location, or rebuilding to a more resilient standard to reduce future risks, is adequately considered by authorities and individuals
>
> (COAG 2011: 12)

However, disaster mitigation is not currently integrated into Australia's disaster relief. While there were isolated examples of relocation following the 2010-11 floods at Grantham, QLD and in the Lower Loddon, VIC, relocation is not a consistent policy and the lack of functional betterment provisions makes it clear that COAG's aspirational objective is far from being realised.

5.6 Information and analysis function

Information on climate change related flooding is abundant, albeit with an emphasis on coastal flooding due to sea level rise. All levels of government, as well as research and training institutions, industry bodies and NGOs are involved in the production and analysis of information related to flooding. This includes impacts of climate change on flooding, guidance material in the form of best practice manuals, tools, information networks, courses and workshops. Governments also have a role in developing guidance to improve the quality and consistency of information. Production of information is often collaborative with a number of different organisations involved and funding opportunities from many different sources. The organisations and the resources they produce are too numerous to detail but some are listed in Table 3.1. Many recent initiatives by led different organisations are also outlined in *Australia's fifth national communication on climate change* (Australian Government 2010*a*).[25]

While information abounds, the SIRP report found that local flood information is often lacking, is not publically available or is not used. This section explores the needs and barriers to obtaining and using basic flood information.

5.6.1 Flood information

Accurate flood information is a prerequisite for the application of planning legislation and instruments that address flood. It also enables risk assessment and implementation of mitigation measures. However, it has proved challenging to gather and incorporate flood information into planning schemes in most municipalities, even without factoring in the added threats of climate change.

In Victoria, 80% of floodplains are reportedly mapped for a 1:100 year event but only 70% of these mapped areas are incorporated in planning schemes (Comrie 2011: 194-195). In

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[25] Initiatives relating to flood can be found on pp.116, 119, 124, 158

Queensland, most towns and cities are built on floodplains. However, a recent review of planning schemes found that only 37% of schemes contained any flood related mapping. Of these, only 23.6% were completed in accordance with the *SPP 1/03 Guideline*. The QFCI concludes this is “a wholly inadequate level of flood mapping” (QFCI 2012: 62).

5.6.2 Barriers to collecting flood information

Possibly the most significant barriers to undertaking flood studies and flood mapping is cost. In Victoria, Catchment Management Authorities have a statutory obligation to provide flood information for councils to incorporate into their planning schemes. However, one CMA that was badly affected by flooding reported that no towns within its catchment had adequate flood mapping, the reason being a lack of a dedicated funding stream (Comrie 2011: 194).

Local Government has the primary responsibility for producing flood studies in Queensland as councils generally hold detailed local information and are the primary users. However, there too, local governments generally do not have sufficient funds or technical resources to undertake flood studies or assess technical information (QFCI 2012: 54-55, 62, 198-200).

Since the 2010/11 floods, the Queensland Reconstruction Authority (QRA) has produced maps for floodplains across the whole of Queensland, which councils can use as interim maps for planning schemes. The maps are intended to provide a basic level of mapping that can be refined by cross-referencing local information (QFCI 2012: 66).

Municipal boundaries do not coincide with catchment boundaries, resulting in flood studies that are done on an individual town or locality scale (QFCI 2012: 55). Yet flood management is most effective on a catchment scale, which raises the issue of whether systems for mapping are fit for purpose (see planning section). Better management outcomes could be achieved if local flood studies were designed to ‘nest’ within an overall catchment study.

SIRP report interviews indicate that the QRA maps have been beneficial in this regard as they have provided catchment-scale maps to local councils that previously hadn’t been able to afford flood mapping. Furthermore, this preliminary work has provided evidence with which local governments can build a business case to obtain funding to undertake more detailed studies. Initial outlays to undertake preliminary flood studies had been a barrier for some local governments. QRA maps have had immediate effect with an example given by one interviewee where a community chose to re-site proposed development to a location that was less flood prone (Wenger *et al*. 2013).

5.6.3 Adequacy of flood information

There can be issues with the accuracy, completeness and currency of flood information (Comrie 2011: 194; QFCI 2012: 56, 193). Flood maps can become out-dated if there are landscape changes, such as new floodplain development, road or levee construction, farming system changes or major floods. These can all change future flood behaviour and cause existing flood information to become unreliable. However, in some states, such as Victoria, there is no requirement for periodic updating of flood information. Recent flood reviews argue that mapping for 1:100 year events is not sufficient from a development planning point of view and events of both greater and lower likelihood need to be included as well, up to probable maximum flood (Comrie 2011: 62-63, 197; QFCI 2012: 63). In Victoria this is already happening and recent flood mapping funded by the Victorian government includes multiple flood levels (Comrie 2011: 62). These recommendations are relevant to the incorporation of climate change scenarios.

When discussing likelihood mapping, the QFCI does not acknowledge that stationarity is likely to cease with climate change and that historical likelihood will no longer be accurate (QFCI 2012: 63-68). This is a notable omission that suggests a lack of comprehension about how climate change is expected to influence future flooding (see also 'The Adequacy of Planning Tools to Accommodate Climate Change' in the Planning Processes section). The Inquiry rates the QRA maps low in its flood mapping hierarchy and questions their usefulness in a development planning context (QFCI 2012: 67, 213-214). The main reason seems to be that the maps identify too large an area of flood-prone land, with no information on likelihood. The Inquiry argues that the large area identified imposes a burden on development applicants. It does not acknowledge that current likelihood values may cease to be valid as a result of climate change.

The QRA maps are based on satellite images, with towns, gauging stations, contours, drainage data and the 2010/11 flood line superimposed. They also include soil (e.g. alluvium) and pre-clearance vegetation information to identify areas that have inundated at some unknown point in history, adjusted using current contour information (QFCI 2012: 66). Arguably, the use of this geological information means that these maps provide a good representation of probable maximum flood levels. The QFCI's reservations about the use of the Authority maps somewhat contradict its enthusiasm elsewhere in the report to identify probable maximum flood levels (QFCI 2012: 63). In his book on extreme events, Jonathan Nott looks at the application of the geological record for predicting floods, noting that particularly in countries like Australia, "short historical records may give a false impression of the nature of the flood hazard for a region". This impacts on community vulnerability as it affects individual and community perceptions of risk and their attitudes towards mitigating against it (Nott 2006: 1-16, 75). While the QRA maps are conservative, understanding past extreme flooding events and watercourses could reduce vulnerability to 'unprecedented' floods that are more likely under climate change. Using the Authority's maps in the absence of more detailed information would enable a precautionary approach to development that would assist climate change adaptation, loosening controls as more information comes to light rather than increasingly tightening them. Moreover, restricting development to conservative levels may provide an incentive to improve the knowledge base through funding flood studies.

5.6.4 Incorporation of future threats into flood information

Adaptation measures to non-stationarity have been suggested by some authors. Milly *et al*. propose higher resolution (more localised) modelling incorporating a wide range of information, coupled with improved information transfer, in both directions, between water managers and climate scientists (Milly *et al*. 2008). This measure would make information more locally relevant and decrease uncertainty. The need to downscale climate change flood information to catchment level has also been identified as a key issue by the Productivity Commission's report on barriers to effective climate change adaptation (Productivity Commission 2012).

Supported by catchment-level information, adaptation to climate change needs to be sensitive to consequence and not just likelihood. The consequence of different climate change scenarios will vary according to catchment due to their different characteristics. More comprehensive flood mapping that incorporates consequence rather than just flood extent[26] could help to understand future risks but its production would be more costly.

Attempts are being made to make climate change information locally relevant. As discussed elsewhere in this paper, a recent joint project undertaken by the Queensland Local Government Association and state government agencies has provided a climate change factor for increased rainfall intensity that can be incorporated into flood studies. However, Hallegatte suggests that improved modelling is unlikely to yield the degree of certainty that planners require, partly due to difficulties distinguishing between natural multi-decadal variability and anthropogenic climate change. Models cannot be validated in the short term, by which time a maladaptive decision may have been made. Moreover, projection ranges continue to be large despite improved information and uncertainty will remain no matter how good the modelling. Hallegatte argues that it is current decision making frameworks that need to be changed to accommodate this uncertainty rather than delaying action until information provides certainty.

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[26] Galloway G E, A California Challenge - Flooding in the Central Valley: A Report from an Independent Review Panel to the Department of Water Resources, State of California, 2007, p.23-24 suggests it is important to map the distribution of risk, including flood depths, existing and future development, including populations, structures, infrastructure and future consequences of flooding.

He ranks adaptation options according to a number of characteristics, including no-regrets strategies, reversibility, ease of incorporating low-cost safety margins, soft strategies (which by their nature are generally reversible), avoiding long term commitment (uncertainties increase further into the future) and synergies, which consider externalities to other sectors. 'Institutionalisation of a long-term planning horizon' is an example of a soft management measure that forces planners to look several decades ahead. Other high priority measures relevant to flood management include climate proofing of new building and infrastructure, restrictive land use planning, insurance and the development of early warning systems and evacuation systems. Structural solutions and options such as relocation and retreat were less favoured, as they were not reversible or flexible (Hallegatte 2009).

Other adaptation measures to address non-stationarity have been suggested by Lee Godden and Anthony Kung. Their paper on regulatory and planning law suggests reforms in these areas could do much to encourage autonomous and private adaptation. They recommend use of incentives and community engagement (Godden and Kung 2011). An example of the use of incentives is given in the final QFCI report, where transition of existing residential areas to lower impact uses is facilitated by a lower level of development assessment (QFCI 2012: 146-147).

5.6.5 Application of flood information

Mapping enables risk assessment and the application of planning measures such as minimum floor levels and zoning to ensure land use is compatible with the level of flood risk. Risks are assessed in the context of a floodplain management plan which considers environmental, social and economic costs and benefits of different measures and acceptability of flood risk (QFCI 2012:40, 60). Both the QFCI and the Comrie Review found lack of financial and technical resourcing for local governments compromised their ability to undertake risk assessment. They concluded greater state government support was needed. State governments also needed to be more active in developing standards and providing coordination (Comrie 2011: 39; QFCI 2012: 60). Victoria's mobile technical support unit is a creative approach to addressing local government capacity issues (Productivity Commission 2012: 131-132).

5.6.6 Availability of flood information

Awareness of flood risk is often seen as a key factor to increase community resilience. If communities and individuals are aware of flood risk in areas they wish to develop or purchase, they will be able to assess their own risks. Problems associated with the provision of information include impacts on land values and insurance prices, intellectual property and liability for incorrect information. Geoscience Australia is currently implementing a *National Flood Risk Information Project*, which includes a national database for flood studies. Thus increased availability of information on flood risk seems to be the direction Australia is headed regardless of current barriers.

While public awareness of flood risk is important to support community resilience, it has its limitations. It is significant that the QFCI found that "purchasers of property, in making the decision to purchase, did not turn their minds to the property's vulnerability to flood" (QFCI 2012: 70). There are also socio-economic implications in that even if risks are widely known, poorer people may not be able to afford the higher purchase price of living in areas with low flood risk. They also have less financial capacity to retrofit or build using flood resistant design. Neither would risk awareness benefit vulnerable people accommodated in aged care facilities, hospitals and childcare facilities, which are also often sited without adequate consideration of flood risk (QFCI 2012: 150). Thus risk awareness is no substitute for good planning and development controls.

5.6.7 Liability issues

Perception of liability can be a significant barrier to the provision of flood risk information and its incorporation into planning schemes by local government. This is particularly the case for climate change information given the uncertainties involved at the local scale (Comrie 2011: 196; Trowbridge *et al.* 2011: 70; QFCI 2012: 128-132). Councils can be exposed to compensation claims if land is 'down-zoned', subjecting it to flood controls and reducing land value. In the SIRP report, one interviewee related a case where almost the entire council budget was spent defending development decisions to prevent coastal development applications from going ahead (in this instance the State Government was obliged to step in). Councils are also liable for losses if they provide flood advice, act or fail to act in respect to flood-prone land (QFCI 2012: 128). This issue is also identified by Gibbs and Hill, who note that some states, such as Queensland, have greater legal provision for compensation than others for councils wishing to apply development controls (Gibbs and Hill 2011).

Some sources suggest a potential liability for the quality and accuracy of flood information (Trowbridge *et al*. 2011: 70). In one case reported by the QFCI, a council decided not to provide any information on historic or current flooding unless an application was made under freedom of information legislation (QFCI 2012: 130). A recent paper by Eburn and Handmer finds that the liability risk of providing flood risk information is vastly overstated and there are "no cases where anyone has successfully sued a council for releasing up to date, accurate hazard information". Rather, councils face liability for not supplying information about known risks (Eburn and Handmer 2012). The QFCI finds it is important that councils not be inhibited by statutory liability to compensation from adopting appropriate regulations and providing information. It makes no formal recommendation on these issues but discusses NSW legislation as a possible solution. Statutory immunity is provided by section 733 of the *Local Government Act 1993 (NSW)*, (recently amended to include climate change information). The application of this legislation is currently being investigated by the Queensland Government. Granting indemnities for information provided in good faith is similarly recommended by the National Disaster Insurance Review.

Water authorities in Victoria are liable to compensate people who incur a loss due to the performance of water authority functions under the terms of the *Water Act 1989 (Vic)*. This could potentially include failure to take climate change risks into account. The authors view this as positive as it could encourage re-assessment of the adequacy of existing planning controls (Godden and Kung 2011).

5.6.8 Conclusion

There are many barriers to the collection and use of locally based flood information. They relate to insufficient local government resources (both technical and financial) to fund flood studies and to defend and compensate development decisions that are made as a result of using that information. Other issues include municipal boundaries that inhibit the production of catchment-scale flood studies, community cost in terms of lower land values and higher insurance costs and difficulties downscaling climate change information. The QRA maps provide a positive example of how some of these difficulties can be overcome.

5.7 Market mechanisms

There are several market based mechanisms that can be useful in achieving improved flood mitigation, including provision of flood risk information to potential property purchasers, insurance incentives and payment for services.

Market mechanisms can be activated by making flood information available. In NSW, information regarding a property's flood risk can be included on its S149 certificate (e.g. Wagga Wagga). These certificates contain information on any development restrictions and conveyance legislation requires them to be attached to contracts for the sale of land.

Insurance pricing can increase awareness of flood risks attached to a property. Insurers are also able to offer incentives to property owners, and even whole communities, to mitigate flood risks through offering lower premiums. However, the industry will need to be careful about what kinds of measures it advocates. Structural approaches to flood mitigation, for example, are not always the best solution and can exacerbate flooding elsewhere or decrease the resilience of those protected by structural works.

Another way in which insurance could help Australia to adapt to flooding would be through new products. For example, in return for a minimal additional premium, some flood insurance schemes overseas offer supplementary payouts to enable more resilient repairs. These issues are covered more fully in the SIRP report.

Payment for services can be used as a means of reducing flood impacts through improved land management. Such schemes compensate property owners such as farmers who allow their property to flood to reduce the impacts of flood for downstream users. This means land use needs to be flood compatible, (e.g. dryland grazing), and land management needs to retain water on the land, through measures such as wetland restoration, use of temporary detention basins and strategic revegetation to slow run-off and assist water infiltration. Such 'flood mitigation' businesses could diversify farm income sources as well as providing a public benefit. In particular, it would be a valuable tool for implementing ecosystem approaches to flood management (see planning section). However, a catchment approach to flood management would be required as flood management measures generally need to be implemented in the upper catchment, while the benefits are found in the middle and lower catchments, and payments would need to be transferred accordingly. Identification of priority areas for improved management would need to be identified within catchments, as well as assessment of the value of that benefit for service users. Pricing would need to be adequate to provide incentives for property owners.

As discussed in the SIRP report, payment for ecological services is an approach used overseas for flood mitigation but it is less well known in Australia. A recent Australian example aims to reduce impacts of flooding including catchment erosion and sedimentation in Moreton Bay, QLD (see planning section). Priority areas for improved land management have been identified and a cost benefit analysis has been done (QCC 2012). According to the proposal's business case, approximately $80 million would be needed over the next three years ($500 million over 20 years). As sedimentation affects water quality and water supply, the scheme would raise the money through household water bills. The catchment levy would cost households $3-$8 per year. Analysis of the area's water dependent industries by Marsden Jacob Associates indicates the economic benefits of this initiative could be considerable. The proposal has been submitted to the State Cabinet.

A further example is Victoria's *Trust for Nature*, a not-for-profit organization that has been involved in developing conservation covenants to protect wildlife on private land. It also facilitates payment for ecological services through Native Vegetation Offset agreements, whereby landowners are paid to protect and improve the quality of native vegetation on their land (Trust for Nature 2012). Thus there are examples of PES in Australia that could help to provide incentives for flood mitigation through improved land management.

6. Discussion: the extent to which adaptive characteristics are evident

Using evidence from the results section, this section assesses the extent to which adaptation characteristics are evident in Australian flood management. Characteristics addressed include:

Clarity of purpose: Requires clear definition and understanding of problems at a system level so that we can address root causes and not just symptoms.

Diversity: Requires a diversity of ideas, skills and resources, a diversity of views, innovation, flexibility in problem solving, and wide inclusion of stakeholders in a purposeful and structured fashion.

Connectivity: Requires institutional (including community) networks that are not susceptible to collapse due to one part failing; effective use of resources; community ability to organise itself; appropriate leadership; spare capacity; and some duplication of functions and overlapping of institutions.

Integration and feedback: Requires a holistic consideration of issues and realistic consideration of scale, accounting for the full range of interactions between humans and ecosystems. It also requires resources to monitor and to promote debate and learning.

6.1 Clarity of purpose

Information about climate change impacts on flooding is not lacking and much work has been done at all levels of government to identify these impacts and assess risks. These are used liberally to justify proposed adaptation activities.

Numerous intergovernmental initiatives, including national strategies, arrangements, agreements, frameworks, action plans and roadmaps provide an agreed national approach to flood problems, including exacerbated risk from climate change. The approach in terms of disaster management is ‘resilience’, which encompasses both root causes and symptoms. As resilience is such a broad term, it is sometimes hard to distinguish the specific aspect of the problem that some measures are intended to address. Some, such as the *National Partnership Agreement for Natural Disaster Resilience*, while ‘sold’ as the Federal Government’s contribution to disaster mitigation, actually address symptoms as well. Contradictory definitions of the word ‘mitigation’ obscure the Agreement’s true purpose. However, some recognized methods of flood prevention are understood and are included in initiatives aiming to adapt to climate change. The prevention focus is on improved development controls. Measures such as relocation appear to be less systematically supported, while ecosystem approaches to flood management (that can help mitigate existing as well as future development) are not yet widely understood.

Inconsistent legislation and processes for addressing flood risk at the state level reflect conflicting development policies. This makes it difficult for different institutions to have a good understanding about what is expected of them in terms of flood prevention and management. This lack of clarity about policy priority in different situations results in a lack of shared responsibility and institutions that work at cross purposes.

6.2 Diversity

Flood management is all inclusive. Evidence from all mechanisms indicates wide stakeholder engagement across different levels of government and portfolios, research institutions, industries and communities, even to the individual level. 'Shared responsibility', promoted by intergovernmental arrangements fosters this involvement.

At the federal level, the strengths of different agencies are combined to implement the *National Flood Risk Information Program*, which works with state governments and local governments to make information about flood available to all. In turn, guidelines produced by the Federal Government aim to improve quality, consistency and comparability of flood information commissioned across the country by other entities. The aim is for everyone to have access to the flood risk information they need to make development, mitigation or purchase decisions.

Examples from local government include climate change alliances. These not only build synergies across other municipalities within a region but also enable better access to federal government grant schemes. Many of them have wide stakeholder involvement including with industry and research institutions to fund adaptation projects tailored to the local level. The Federal Government has actively supported such partnerships through grants schemes such as LAPP.

Issues arise at the local level due to resourcing constraints. Many do not have the means, either financial or technical, to undertake flood studies or assess flood information. The Productivity Commission suggests that this could lead to shortcuts in decision making processes that are otherwise costly in time and effort (Productivity Commission 2012: 109-110). For adaptation to actually be implemented there needs to be a wide skills base and financial resources on the ground, coupled with strong policy leadership and guidance from state government.

6.3 Connectivity

Networks related to flooding are of varying robustness. The 'bottom up' networks studied in this paper, such as local government alliances and natural resource management bodies appear very strong and effective. They involve large numbers of stakeholders and have a diverse funding base; the loss of one will not make a large difference. While their objectives continue to remain relevant and they continue to deliver results, they are unlikely to fail.

Not all networks are as successful. The vast majority of recommendations in recent flood reviews pointed to a need for better governance, coordination, integration, accountability, oversight, communication, and other socio-institutional issues. Administrative systems, operating as networks across portfolios, do not always function effectively. As demonstrated in the section on intra-governmental function, network failure resulted in non-compliant planning schemes that did not incorporate flood controls. This is likely to be a consequence of conflicting portfolio agendas and a lack of policy leadership.

While duplication and overlap seem to have occurred in some areas, this is not always useful. The strategies, plans and arrangements in place for emergency management are profuse and somewhat confusing to negotiate. It seems likely that some, such as the *National Framework for Disaster Resilience* might be redundant now that the more detailed NSDR is in place. The complexity may have led to some strategies being overlooked or given only cursory attention. Implementation of the MCPEM *Climate Change Adaptation Plan*, for example, appears to be less than thorough.

Information and analysis is of great importance as a prerequisite to implementation of climate change adaptation. The production of this information is from diverse sources, with multiple sources of funding that address the needs of different stakeholders. In this instance, overlap is positive, in that a broad range of strategies can be explored and all sections of society can be reached. However, there are problems associated with the vast number of tools, approaches and methodologies available to managers, in that it causes confusion about which to use (Productivity Commission 2012: 129).

6.4 Integration and feedback

Floods are not only disasters. Australia's carryover water storage system depends on them. Managed well, flooding can replenish groundwater, restore ecosystems and boost economies. How Australia manages floods will be vital for its adaptation to other climate change impacts such as drought.

Currently Australia does not capitalise on its flood opportunities. Highly regulated water management in Australia eliminates smaller high-frequency floods, which might otherwise replenish watertables and restore natural assets. Not only does this reduce Australia's preparedness to deal with large magnitude events but it can also increase the negative impacts of large scale events, for example, resulting in blackwater events[27] and degraded, unconnected wetlands that are less able to mitigate flooding.

Another issue hampering the management of floods is that humans and ecosystems function with different geographic and temporal boundaries. Flood management needs to consider whole catchments and cumulative impacts when assessing development and flood mitigation alternatives. Unless planning and management can be carried out on a catchment scale by organisations with sufficient technical expertise and a long term perspective, the interaction between floods and humans will continue to be harmful.

Legislation and development planning systems currently have an inconsistent approach to flood risk. Opposing policy objectives, such as affordable housing and short term financial concerns conflict with concerns about flood safety and long term damage costs. This reflects a lack of policy leadership about approaches to flood risk by state governments. The situation is not assisted by current arrangements for payment of damage costs, which are largely paid for by the Federal Government, thus externalising the consequences of this lack of leadership. If policy conflicts are not resolved, flood costs will continue to grow under climate change scenarios, compromising Australia's economy and the wealth of its citizens. The money that could have been spent on mitigating climate change and developing adaptive strategies will be wasted on avoidable damage costs.

As discussed earlier in this paper, policy conflict is not confined to state governments. Recent development projects located in flood prone areas have also been funded through the Federal Government's economic stimulus package. Leadership is required at all levels to resolve policy conflicts and to develop consistent legislation and planning processes accordingly.

The Federal Government has been making increasing efforts to address prevention through coordination and leadership of initiatives such as the *Enhancing Disaster Resilience in the Built Environment Roadmap*. However, some of the government's stated objectives, such as the integration of climate change impacts into the *Building Code of Australia*, have so far failed

[27] Blackwater events occur during floods as a result of rapid breakdown of organic matter. This depletes dissolved oxygen levels in the water (also causing water discoloration) and commonly results in fish kills. Blackwater events are worsened by higher temperatures that accelerate the decay of matter. Blackwater events are believed to have worsened due to water regulation which eliminates small floods thus allowing longer accumulation of large amounts of organic matter. This is expected to be exacerbated by prolonged droughts associated with climate change.

(Australian Government 2010*a*: 119; Productivity Commission 2012: 155). The Federal Government's current focus on resilience, which covers all aspects of flood management, obscures a desirable emphasis on prevention. Moreover, prevention needs to be better integrated into the Federal Government's disaster recovery efforts. Simply rebuilding is 'reinvesting in disaster'[28].

Activity on all levels contributes to information about flooding and key aspects, such as weather patterns and projected climate change impacts continue to be monitored and reported by organisations such as the Bureau of Meteorology and CSIRO. This information is used as a basis for research, debate and action. Ecosystem researchers and state government natural resource management agencies are investigating the potential for ecosystem approaches to flood management (DSE 2012*a*; Queensland Government 2012*a*). However, there is a current divide between floodplain managers with a natural resource management background and flood managers with an engineering background. Professional training needs to be better integrated so that there is consideration of all options on a case by case basis. Methods of cost benefit analysis have been developed overseas to compare the merits of flood mitigation options and these could be applicable for use in Australia.

Flood reviews are a major feedback mechanism and these were studied comprehensively in the SIRP report. The report found that none of the reviews studied by the project included climate change in their terms of reference and only ad hoc mention was made of climate change in the body of the reports. Consideration of the adequacy of arrangements in place to address flooding was retrospective rather than considering future conditions (Wenger *et al*. 2013). This narrow analysis of events will be of limited value in helping Australia to adapt to future threats. Review of the performance of the QRA as a model for flood recovery would be beneficial as initial indications are that it has focused efforts and achieved several successful outcomes, including basic flood mapping for all Queensland floodplains, and amending planning provisions to facilitate the relocation of the town of Grantham.

7. Conclusion and recommendations

The current approach of flood management in Australia is 'resilience' and through federal leadership and funding, it has been adopted throughout the country. While partly a rebranding of PPRR, resilience also attempts to promote shared responsibility for disasters. It is yet to be seen whether the community will accept this responsibility (and remember it during periods of prolonged drought). However, given that flooding is expected to worsen, and that response

[28] Charles L. Hardt, Tulsa Public Works Director, 1993. In NWF, 1998: p.144.

capacity will be stretched in large magnitude floods, greater self-sufficiency would be a sensible adaptation if it can be achieved.

Climate change adaptation is a stated rationale for resilience, though it is not referred in key funding mechanisms, such as the *National Partnership Agreement for Natural Disaster Resilience*, or in most annual state implementation plans. However, these funding mechanisms and others have enabled the development of risk assessments and adaptation plans, as well as community awareness raising and development or revision of key flood management tools. At this early stage, it is difficult to determine whether the resilience approach enables effective adaptation to flooding. In view of the paucity of funding of the National Partnership Agreement and its vast scope, it seems doubtful that it will have a greater impact than its predecessor, the *Natural Disaster Mitigation Program*. Other elements of NSDR implementation, such as the *Enhancing Disaster Resilience in the Built Environment Roadmap* are innovative and hold promise. However, major opportunities to incorporate climate change risks into planning controls through the *Building Code of Australia* have been missed.

Perhaps one of the most significant initiatives to so far come out of the resilience approach is the greater availability of flood risk information through NFRIP. This could prove to be a major step forward in awareness of flood risk and the need to mitigate.

To adapt to climate change, Australia needs to ensure it maximizes the benefits of large and small floods, while minimizing the adverse consequences of large floods that result from poor management. Floods are vital for Australia's water security and this will only become more important during the prolonged droughts anticipated as a result of climate change. Analysis in this paper suggests that aspects of flood management most in need of attention are:

- assessment of the adequacy of current planning instruments to accommodate climate change;
- consistent policy, legislation and planning processes to ensure that future flood risks are assessed and addressed;
- sufficient resources for local government (both technical and financial) for on the ground flood prevention and mitigation;
- significant increase in funds available to flood prevention/mitigation to reduce long term damages, in particular for:
    - basic nationwide flood mapping;
    - sophisticated flood mapping in urbanised and developing areas that includes worst case scenarios, projected population and development and flood consequences;

    - improved development planning;
    - relocation of those most at risk and reassignment of land to flood compatible uses;
    - recognition and support for ecosystem approaches;
- flood recovery strategies that merge with prevention to increase future resilience;
- administrative structures that enable a catchment based approach to flood management; and
- integration of ecosystem approaches into training for flood managers, coupled with community education programs.

Major impediments to achieving these objectives include conflicting development policy objectives, many of which value short term development gains over long term disaster prevention; the non-mandatory nature of many current provisions relating to flooding; insufficient investment in prevention (as opposed to relief and recovery); disincentives such as badly targeted flood relief and lack of financial consequences for those making risky development decisions; planning that is based on administrative boundaries rather than natural geographic ones; planning tools that are inadequate to address future risks; and inadequate resourcing, particularly for on the ground implementation. Potential financial consequences are a major barrier that inhibit local government from using flood information and applying appropriate land use and development controls, particularly if this means land has to be 'downzoned'.

In order to achieve improved flood management, reforms will be needed at all three levels of government. At the federal level, funding needs to be targeted at preventative measures that will reduce future damage bills, such as the better integration of disaster recovery programs with mitigation of future risks. The current focus on risk assessment that addresses consequences is sound. However, the amount of money available to mitigate flood risk needs to be vastly increased. Stronger options to encourage improved land use and development planning, such as reduced federal investment in regions with inadequate controls could be explored if current cooperative approaches prove insufficient.

All three levels of government need processes to resolve policy conflicts that compromise the consistent application of flood prevention measures both within and between levels of government. Intergovernmental agreement on policy precedence could buffer shifts in priority as a result of short term changes of government. At the time of writing, the ANZEMC Roadmap is not yet publically available but it is expected to include 'integrated legislation'. It could be the first step in this process and needs to be given high profile support. If a consistent national approach to resolve these issues cannot be achieved, dialogue about policy conflicts and which should take precedence in different situations needs to take place, and this needs to be clear to decision makers on the ground. When considering which policy should take precedence in a given instance, the full costs of policies need to be considered, including intangible and future costs. These policy priorities also need to be reflected consistently in state planning legislation and investment decisions. Crucially, it is important that state and local governments are not financially penalised or disadvantaged for good decision making. For example, regional development funds could be offered by federal or state governments where appropriate controls are in place and enforced.

State / territory planning processes could be improved to enable facilitate adaptation. Rather than relying on modelling to provide greater certainty about flood risk, improved decision making systems need to be implemented that enable low cost, flexible approaches to flood risks. Local governments also need to be better supported by state governments in terms of technical capacity and financial resources for generation of flood information and risk assessment. Appropriate legal protection or financial capacity to pay compensation when it is necessary to down zone could encourage the actual application of flood information.

Catchment-based approaches to flood mitigation could potentially be achieved cooperatively between councils. However, a council's responsibility stops at its administrative boundary and so catchment management is better implemented at the state level. In Victoria, CMAs have a formal role in the development approval process. However, not all states have administrative structures that support an integrated catchment based approach to development planning and flood mitigation. Nevertheless, much could be done to enhance catchment based approaches in other states, in terms of mapping, assessing cumulative impacts across entire catchments and implementing appropriate measures in the parts of the catchment that would be most beneficial. This could be paid for by market mechanisms, that also need to be coordinated on a catchment scale. This is most appropriately done at state level.

In a country with very short term records of past floods, the use of flood mapping that incorporates palaeological information about past flood events, such as the QRA maps, will enable better assessment of possible worst case scenarios and identification of potential flow paths. QRA flood maps are low resolution but have already resulted in proposed development being relocated to less risky areas. This exercise could well be duplicated across the country to provide basic, cost effective flood mapping to communities that have never been able to afford it. This would need to be coordinated by state/territory governments, and would probably require Commonwealth funding assistance. As likelihood of flooding is predicted to increase, consideration should also be given by state/territory governments to the use of more conservative planning tools, such as higher floor levels and building material and design, particularly for areas that will suffer largest consequences of flooding, such as urban areas or development in confined catchments.

A review of the QRA and its effectiveness in facilitating recovery options that mitigate against future risks would be beneficial to inform future recovery efforts. This could be done by either the Federal Government (which provided funding to QRA) or by the Queensland State Government.

Local government needs to ensure it has adequate flood risk information on which to base decisions, and to incorporate this into planning schemes. Councils also have a responsibility to make information freely available as it is only when information is available that flood risks can be addressed. Community resilience objectives will not be achieved in the absence of this information.

Local government alliances can greatly facilitate the capacity of local governments to adapt to climate change. They can promote synergies, help leverage funding, advocate adaptive approaches and be a vehicle for locally relevant research and action. Such alliances have good coverage in some states, such as Victoria, where they were initially funded by the State Government, but less coverage in others. More alliances in other states could greatly benefit adaptive capacity of local governments and the development of locally relevant solutions.

Local government also has a large role to play in community education. Flood damage often results in activity by communities and landowners, such as channel straightening, building embankments and vegetation clearance, that actually increase the potential for future flood damages. Local governments have a role in communicating optimal strategies for minimising flood damage and for ensuring that local activities do not worsen flooding downstream. This could be supported by NRM bodies in each state. These conclusions are summarised in Table 3.2, below.

Table 3.2: Reforms to improve adaptive capacity for flood risk.

Problem	Barriers	Reform Needed	Responsibility
Rebuilding to pre-existing standards does not increase resilience to future flooding	Additional upfront recovery costs versus lower long term damage costs. Need for immediate restoration of infrastructure that precludes lengthy cost-benefit analysis processes.	Flood recovery processes that merge with prevention. Need for agreed processes with local governments to pre-approve infrastructure suitable for betterment.	Federal.
Insufficient funds for flood prevention / mitigation versus generous funding of relief and recovery	Lack of understanding about the long term cost effectiveness of preventative approaches, coupled with short parliamentary terms of office: responsible spending is unlikely to receive due credit. Political gains in the short term from a well-coordinated emergency response; negative media coverage if efforts are insufficient.	Increased funding of prevention, particularly for: • flood information • risk assessment • improved development planning • relocation of those most at risk and reassignment of land to flood compatible uses • ecosystem approaches. Strong promotion to the public about the benefits of prevention and action governments are undertaking. Establish relevance to all Australians, not just those in flood prone areas (i.e. higher tax and insurance premiums for all).	All levels of government, particularly the federal level through the NSDR.
Non-mandatory consideration of flood risk in development legislation and processes	Conflicting policy objectives Short term versus long term gains Lack of flood mapping Length of time before key instruments are due for revision	Consistent policy, legislation and planning processes to ensure that future flood risks are assessed and addressed. Mandatory inclusion of flood controls in local planning schemes. Nationwide investment in cost-effective, basic flood mapping, such as QRA maps.	State government is responsible for policy, legislation, processes. Investment in large scale mapping exercises may need federal funding support.

Problem	Barriers	Reform Needed	Responsibility
	and complex processes for regular update and inclusion of flood information.	Processes to facilitate prompt inclusion of new flood information into local planning scheme.	Local government responsible for inclusion of flood risk in planning schemes. Federal government needs to ensure its own development projects consider flood risk.
Inadequate incorporation of climate change into planning tools[29]	Flood modelling does not provide adequate certainty for local decision making.	Better incorporation of climate change into building codes, at both national and state levels. Assessment of adequacy of de facto standards, such as the 1:100 year flood event for climate change. Incorporation of palaeological information in mapping to increase awareness of potential flood area and to compensate for short flood records (e.g., QRA maps). Use of decision making systems that do not rely on information certainty. E.g. adaptive approaches can be identified that are low cost, ‘soft’, no-regrets, reversible, etc. Alliances that pool local government resources to improve adaptive capacity.	Primarily state government. Local government can improve on low resolution mapping where required, and implement adaptive decision making systems. Climate change alliances could be formed independently by local government but initial funding support by state government would facilitate this.

[29] Note attempts are currently underway to incorporate climate change into planning tools, such as the Queensland Government’s climate change factor and the AR&R Revision Project (undertaken by Engineers Australia and funded by the Federal Government).

Problem	Barriers	Reform Needed	Responsibility
Inadequate on-the-ground application of land use and development controls	Lack of clarity about policy priorities from state government Insufficient resources for local government (both technical and financial) for on the ground flood risk assessment, prevention and mitigation Negative financial consequences of responsible decision making when land is down-zoned (e.g. reduced rates, legal action and compensation liabilities) Lack of financial consequence for those who make risky decisions[30]	Improved clarity and guidance about policy priorities within and between governments Improved resourcing and technical support for local governments Incentives and better financial or legal support for responsible decision making and implementation of measures Reduced investment in communities that do not implement adequate controls	Primarily state government, though Commonwealth also has a role in provision of financial resources
Flood risk information is not freely available	Financial consequences for landowners (e.g. drop in land values, rise in insurance premiums) Financial consequences for local governments if they apply the information – see above (if information is public they will be expected to use it)	Being addressed through the National Flood Risk Information Program ANZEMC Roadmap is expected to look at issues such as vendor disclosure	Local government

[30] Higher standards should apply to well-resourced urban communities than to rural communities which have fewer resources, and where consequences of flooding are lower

Problem	Barriers	Reform Needed	Responsibility
Implementation of maladaptive approaches to flooding	Localised implementation of flood control where those undertaking activities are unaware of or unconcerned about negative off-site effects Effective flood mitigation measures are sometimes counter-intuitive (e.g. vegetated, meandering waterways containing debris reduce flood damage but the temptation is to clear and straighten)	Administrative systems that support a catchment based approach to: • collection of flood information, • assessment and implementation of flood mitigation measures (considering cumulative impacts and positive and negative externalities) • development planning and application of market mechanisms such as PES Raising community awareness about most effective flood mitigation measures Broad stakeholder engagement is needed for optimal outcomes across sectors.	Primarily state government, though the Commonwealth also has a role in provision of financial resources

ACRONYMS AND GLOSSARY

Acronym	In full	Comment
ABCB	Australian Building Code Board	Develops minimum national building and plumbing standards.
AEMA	Australian Emergency Management Arrangements	Articulates emergency management responsibilities.
AEMC	Australian Emergency Management Committee	Former name of ANZEMC.
ANZEMC	Australia-New Zealand Emergency Management Committee	Reports to SCPEM.
COAG	Council of Australian Governments	Peak government body.
CMA	Catchment Management Authority	State agencies with boundaries defined by natural catchments. Only some states have CMAs and they have varying powers.
DCS	Department of Community Safety (QLD)	An agency with a role in flood approvals at the time of the 2010-11 floods.
DERM	Department of Environment and Resource Management (QLD)	An agency with a role in flood approvals at the time of the 2010-11 floods.
DFE	Defined Flood Event	A development planning tool based on a past flood event, generally close to the 1:100 year event.
DLGP	Department of Local Government and Planning (QLD)	An agency with a role in flood approvals at the time of the 2010-11 floods.
ENRC	Environment and Natural Resources Committee	Responsible for the Inquiry into Flood Mitigation Infrastructure in Victoria.
LAPP	Local Adaptation Pathways Program	A federal grants program to assist local communities adapt to climate change.
MCPEM	Ministerial Council for Police and Emergency Management	Former name of SCPEM.
NCCARF	National Climate Change Adaptation Research Facility	An agency that funds research into climate change adaptation to assist policy makers, business and the community.
NEMC	National Emergency Management Committee	Former name of ANZEMC.
NFRAG	National Flood Risk Advisory Group	Reports to ANZEMC.
NFRIP	National Flood Risk Information Program	A federal program aiming to increase availability of flood risk information.
NDRRA	Natural Disaster Relief and Recovery Arrangements	Cost share arrangements between Commonwealth and state governments in the event of a natural disaster.
NSDR	National Strategy for Disaster Resilience	Guides Australian natural disaster policy.
PPRR	Prevention-Preparation-Response-Recovery	A commonly used emergency management framework. 'Prevention' includes mitigation and refers to eliminating or reducing the hazard or increasing the ability to withstand it. Flood information and risk assessment are prerequisites to the implementation of

Acronym	In full	Comment
		prevention measures. 'Preparation' reduces impacts by ensuring hazard awareness and appropriate human response.
QFCI	Queensland Floods Commission of Inquiry	An inquiry body established following the 2010-11 floods.
QRA	Queensland Reconstruction Authority	Established for a limited term to lead reconstruction efforts in Queensland following the 2010-11 floods and Cyclone Yasi.
ROC	Regional Organisation of Councils	An alliance of local governments to address specific regional issues.
SCCG	Sydney Coastal Councils Group	A ROC studied for this report.
SCPEM	Standing Committee on Police and Emergency Management	Reports to COAG.
SIRP	Synthesis and Integrative Research Program	The NCCARF program that funded the 'Living with Floods' report. This paper, also funded by NCCARF, draws on that report.
SPA	Sustainable Planning Act 2009 (QLD)	The primary legislation regulating development planning in Queensland, under which the Queensland Planning Provisions were drafted.
SPP 1/03	State Planning Policy 1/03	The most important Queensland planning instrument to ensure consideration of flood risks in development applications. Due for revision 2013.

Publication 4 preamble

Wenger, C. 2014. 'Sink or Swim: alternative approaches to flood disaster reconstruction and mitigation', in *River Basin Management in the Twenty-First Century: understanding people and place,* (V. Squires, H. Milner and K. Daniell, eds), CRC Press, Boca Raton, Florida, pp. 418-445.

Publications 1 and **2** revealed that ecosystem based measures are popular overseas. They appear highly adaptive as they reduce flood impacts, do not transfer flood problems elsewhere and they provide co-benefits. Relocation is often a prerequisite of ecosystem based measures and it is sometimes implemented as part of preventative recovery (often called betterment in Australia). Institutional arrangements in Australia that relate to ecosystem based measures and preventative recovery were therefore a key concern for **publication 3**.

Publication 3 found impediments to ecosystems based approaches. These included flood management arrangements based on administrative boundaries (rather than catchment boundaries) and the lack of legislative authority of catchment based bodies in development planning. These hindered the use of ecosystem based approaches, as did other factors like lack of public understanding of hydrology. This work also found that Australian mechanisms for betterment, while technically supported by the National Strategy for Disaster Resilience and implementation mechanisms such as Natural Disaster Relief and Recovery Arrangements, were ineffective (and at the time of the 2010-11 floods had never yet been used). Moreover, the amount of money allocated to mitigation seemed grossly inadequate.

Publication 3 only took a cursory look at relocation and house raising. However, background reading uncovered some unexpected details that merited further research. In particular, Queensland's disaster resilience funding guidelines stipulated that prevention activities such as house raising and relocation were *ineligible* for grant funding. Instead, funding guidelines were geared towards structural mitigation. As one of the most lauded flood recovery activities was the relocation of Grantham this seemed surprising. Despite claiming credit, it seemed the Queensland Government was determined not to make this a standard approach.

Relocation is important in other case study countries for achieving ecosystems-based approaches such as room for river and flood compatible land use. Australia's lack of investment in relocation therefore seemed problematic. Questions arose. Firstly, why was relocation used overseas but little used in Australia? An obvious answer was cost. Many reports I had read indicated that this was a major impediment. So what made it feasible elsewhere? The only suggestion I uncovered to explain this was a difference in the way costs and benefits were calculated, for example, whether this was based on the depreciated value of a building or its replacement cost (BTRE, 2002). This did not seem a convincing (or at least, not a complete) answer. I therefore decided to investigate relocation more thoroughly as this seemed a major issue for achieving policy transfer of adaptive approaches.

Publication 4 examines approaches that seem adaptive elsewhere in order to assess the potential for policy transfer to Australia. It looks at relocation examples in Australia and overseas, including the incentives, governance structures and program delivery processes that surround this activity.

Figure 4.1:
"We shall not be moved"
Forced relocation that does not benefit participants will be resisted. Bad development decisions are hard to reverse.

(Photo: E & C Wenger)

Sink or Swim: Alternative Approaches to Flood Disaster Reconstruction and Mitigation

Caroline Wenger

Synopsis

Climate change and population growth are expected to worsen flooding globally, leading to escalating recovery costs that countries can ill-afford. Improving disaster resilience as part of post-disaster recovery is crucial to minimising these losses.

The first section, *Building Back Better*, looks at disaster costs following recent Australian floods. It examines post-disaster reconstruction policies in three different countries and the legislative and funding provisions that support them. Relocation is identified as a significant strategy in some countries.

Ecosystem Approaches to Flooding highlights an innovative resilience strategy used in many parts of the world that not only reduces flood risk but is also expected to buffer the effects of climate change. It generally involves relocation or changing land use. Discovering what makes a successful relocation scheme is thus important to implementing this approach. In contrast to some of the other countries studied in this chapter, achieving relocation in Australia is a challenge. Recent Australian examples of relocation are studied in the final section, Relocation Policies in Australia, and timing, funding, and social factors are all found to be significant for success.

In the Discussion, lessons are drawn from all sections and countries on how to achieve improved flood resilience, particularly for countries such as Australia, where barriers such as cost impede the incorporation of betterment into post-disaster reconstruction.

Keywords: Australia, China, Dongting lake, ecosystem approaches, flood hazard mitigation, floodplains, land swap, legislation, levees, Murray-Darling Basin, New South Wales, polders, post-disaster reconstruction, Queensland, Regge River, risk assessment, 'room for river' measures, sea level rise, The Netherlands, USA, Victoria, wetland, Yangtze River

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1. Introduction

Legally, rivers are defined by their banks, but in ecological terms, rivers also consist of the areas they occasionally swell into: their floodplains, ephemeral tributaries and anabranches (Taylor and Stokes 2005; Wenger *et al*. 2013). Perhaps because humans and rivers exist within different timescales, people think of such areas as being land and rarely recognize them as being part of the river. Floodplains attract settlement because of their alluvial fertility, access to drinking water, river transport, and resources such as fish. However, these bounties come at a cost and periodic inundations destroy assets, lives and livelihoods. Over time, towns and cities may form around vulnerably-located pioneer dwellings, land use changes and exposure to flood grows (Smith 1998; Squires, this volume). Floods are a consequence of a complex interplay between climate, hydrological cycles, catchment topography and human land management. Factors that can worsen flooding of human settlements include:

- **narrow catchments or bottlenecks:** water has less room to spread and can rise rapidly and to great depth even in modest floods;
- **dry catchments, vegetation clearance and urban development:** increase the amount and speed of run-off, and increase erosion and sediment movement;
- **subsidence:** can be caused by extracting groundwater or draining wetlands;
- **hotter climates:** higher sea surface and air temperatures result in greater evaporation and an increased water holding capacity of the air. Thus greater quantities of rain fall in intense bursts. Continental ice melt raises sea levels. Seasonal snow melt accelerates, flooding river valleys;
- **structural measures to prevent flooding such as flood levees and flood gates:** cut off rivers from their floodplains and wetlands, reducing the overall flood storage capacity of the landscape; and
- **inappropriate development:** where inadequate controls are in place, land use and development form may be incompatible with the flood prone nature of the land, resulting in losses.

People living on floodplains have traditionally chosen localised measures, such as raising houses on stilts or mounds, or building flood barriers and drainage channels to reduce damages. However, such measures are only effective locally and some of them exacerbate flooding within the catchment as a whole. Modern flood management has broadened adaptation options through the use of non-structural measures, such as development planning, insurance, management, flood warnings, preparation and awareness (White 1945).

Flood management is commonly divided into different phases, broadly 'before the flood', 'during' and 'after'. Thus flood information, risk assessment, flood hazard mitigation/ prevention, human awareness and preparation all come before a flood, response during, and relief and recovery after. When prevention is incorporated into recovery it becomes a less linear model. The linking of these two phases is often neglected and this chapter will explore some options for achieving this outcome.

Flood risk is managed by governments in various ways. At the more coercive end of the scale, legislation may be used to regulate development and to protect catchments, vegetation, soil and water resources. In some countries legislation is accompanied by penalties such as prohibiting government investment or disaster relief in non-compliant jurisdictions. Other tools are more cooperative and exhortative, and can include whole of government strategies, partnership agreements and formalised arrangements that articulate responsibilities and funding by different levels of government and other stakeholders. Policies, procedures, guidelines and standards assist on-the-ground managers to determine which measures should be used, how and under which circumstances. The generation and provision of flood risk information is another significant government role. The government level at which these functions are performed and the mix of tools used varies from country to country. Market mechanisms can also be used to manage flood risk, and various private sector industries have a role in influencing policy and on the ground management (Handmer and Dovers 2007; Wenger 2013).

In recent years the capacity of current flood management techniques to cope with future threats has come into question as damage costs continue to rise. Population growth, urbanisation and climate change are increasing flood risks globally and increased flood frequency, variability and severity is expected for the majority of major global river basins. The Murray-Darling Basin in Australia could be one of the worst affected, with a recent multi-model study indicating that a twentieth century 1:100 year flood may occur as often as every ten years by the late 21st century (Bates *et al*. 2008; Jha *et al.* 2012; Hirabayashi *et al*. 2013; Munich RE 2013). In 2010–11, eastern Australia experienced some of the most damaging floods on record, with 80% of Queensland declared a disaster zone (QFCI 2011). However, comparison of Australia's flood prevention and recovery policies with those overseas indicate an over-reliance on outdated approaches that will do little to minimize future flood risk.

Following the 2010–11 Australian floods a number of reviews were generated that explored the factors contributing to losses, providing an opportunity to investigate how Australian policy compares with those of flood prone countries elsewhere. In this study, Australian flood reviews, government policy and grants documents were analysed. These were compared with similar documents and case studies from the Netherlands, China and the United States of America to gain insights into how Australia could enhance its resilience to future flooding (Wenger *et al*. 2013).

Analysis of overseas flood policy and reviews showed that all have a strong traditional reliance on structural means of flood mitigation such as levees and flood gates. However the limitations of using these approaches in the face of future risks are now apparent. While levees can reduce flood losses for smaller floods, if they breach or overtop during large floods, damages are likely to be worse than if there had been no levees. Levees also adversely affect water quality, catchment-wide flood risks and ecosystem health. These problems have led to numerous reforms in flood management overseas, such as more rigorous land planning, incorporation of resilience into rebuilding and ecosystem approaches that recognise accommodation of floods as a legitimate land use (Wenger *et al*. 2013). Attempts have been made to achieve some of these approaches in Australia, but most are hampered by lack of coordination between jurisdictions, conflicting policy objectives and an unwillingness to invest in flood prevention (Wenger 2013). This chapter will explore some of the measures that countries are using to improve their flood resilience, with a particular focus on relocation and disaster recovery funding.

2. Building Back Better or Reinvesting in Disaster?

Countries vary widely in their approach to recovering from major floods. In Australia, recovery is funded primarily through the Natural Disaster Relief and Recovery Arrangements (NDRRA) grants process, with the proportion of assistance funded by the Federal Government dependent on the cost of damages. For large scale disasters, the cost share arrangement between governments is 75% federal: 25% state. This primarily funds public infrastructure replacement but not private losses, which are expected to be recouped through private insurance. Government and insurance expenditure following the 2010–11 floods was over A$10 billion (Table 4.1). This figure does not include uninsured losses, but it does include some indirect costs such as emergency accommodation. A breakdown of damage and loss in different sectors indicates substantially greater losses, close to $20 billion for Queensland alone (Table 4.2). For a country with a population of 22.5 million, costs have been enormous.

Table 4.1. Recovery expenditure following the Australian floods of 2010–11.

Recovery Funding Source	Expenditure A$ ('000,000,000)	Source
Natural Disaster Relief and Recovery Arrangements (QLD)	6.8*	(QRA 2011*d*)
Natural Disaster Relief and Recovery Arrangements (VIC)	0.90	(VAGO 2013)
State of Victoria (additional to NDRRA cost share amount)	0.071	(VAGO 2013)
Flood insurance (QLD)	2.388	(ICA 2013)
Flood insurance (VIC)	0.1265	(ICA 2013)
Charitable donations (QLD)	0.266*	(QRA 2011*d*)
Total	10.5515	

* These figures do not separate flooding and Cyclone Yasi

Table 4.2. Estimated damage and loss by sector following 2010–11 floods and Cyclone Yasi (QLD).

Sector	Damage & Loss A$ ('000,000,000)
Mining	5.7*
Infrastructure	5
Housing	4
Commercial properties	2
Agriculture	1.6
Tourism	0.6
Total	18.9

* Loss at the end of the financial year 30 June 2011. The coal sector had only recovered to 75% as at May 2011, so this is likely to be an underestimate of total losses (QFCI 2012). The remaining figures were provided in a joint report by the World Bank and the Queensland Reconstruction Authority (The World Bank 2011).

Recovery funds following the 2010–11 floods only restored assets to their previous condition which exposes Australia to the risk of incurring repeat damages. Reviews prepared following the floods reveal that at the time they were written, 'betterment', or rebuilding to a more disaster resilient standard, was theoretically eligible through NDRRA, but no betterment project had ever been approved (Comrie 2011). A once-off betterment fund for Queensland infrastructure has since been announced (Gillard 2013*a*), but this is not standard policy. In June 2013, the Victorian State Government reported it had not received funding for betterment projects it submitted in 2011[31] (VAGO 2013). If the return period for large floods decreases due

[31] 23 betterment projects for public infrastructure were submitted in September 2011, the betterment component of which totalled A$13.3 million, or 28% of total project costs.

to climate change, the lack of federal investment in resilient reconstruction will make Australia increasingly vulnerable to future damages.

By contrast, Chinese disaster recovery aims to improve its future capacity to withstand floods. A series of floods along the Yangtze in the 1990s culminated in catastrophic floods in 1998 that killed over 4,000 people. Cities along the Yangtze, such as Wuhan, sustained enormous damage. Following the floods, relocation emerged as a significant policy to reduce the cost of future flood damages. Farming communities were relocated out of wetlands to increase the capacity of the landscape to store floodwaters (see 'ecosystem approaches' section) and relocation was incorporated into a package of measures to reduce future susceptibility to flooding, involving substantial funding commitments. US$3.2 billion was allocated for floodplain management and $30 billion for improved land management in upper catchments. While legislation made relocation mandatory, compensation was available and subsidies, such as the "Grain for Green" scheme, provided farmers with immediate livelihood benefits that enabled them to transition to flood compatible land uses (Wenger *et al.* 2013).

In the USA, the cost of repetitive damage provides the Federal Government with a strong incentive to invest in buyback as it is liable for insurance claims to private properties in flood prone areas through its National Flood Insurance Program (NFIP). This program represents the second highest potential demand on the federal treasury behind social security (Wright 2000). There is less financial incentive for Australian governments to fund voluntary purchase, as in Australia it is private individuals and insurers that are responsible for costs of rebuilding private assets. Insurance payouts only cover the cost of the actual damage, and are therefore not sufficient to fund an improved standard of repair, or assist residents to relocate.

Research from the USA into repetitive damage is compelling. In one study, cumulative damage costs were worth up to seven times the value of the original property (NWF 1998). In 1993, floods in the upper Mississippi caused a major shift in disaster relief and there was a "consensus that rebuilding or restoring to pre-flood conditions was not an acceptable policy position" (Wright 2000). During the 1990s, recovery and mitigation became increasingly integrated in the United States and for some disasters they completely merged. With the *Hazard Mitigation and Relocation Assistance Act (1993)*, mitigation funding increased, and 15% of all federal disaster assistance funds became available to be spent on relocation, elevating structures and land acquisition. In some cases this meant whole communities could be relocated (Wright 2000: 69, 78–79).

The conditions for voluntary purchase in the USA include the complete removal of structures and a requirement that land purchased revert permanently to open space uses compatible with fulfilling 'natural and beneficial floodplain functions', such as recreation and flood mitigation (FEMA 2010). The *Hazard Mitigation and Relocation Assistance Act (1993)* prohibits any future federal expenditure on disaster relief or rebuilding on land purchased through the program. Other legislation relating to relocation is found in Section 555 of the *National Flood Insurance Reform Act (1994)*. This requires that communities participating in the National Flood Insurance Program (NFIP) adopt laws requiring that 'substantially damaged' properties (where cost of reconstruction is equal to or greater than fifty per cent of the pre-flood market value of the property) be elevated to the 1 in 100 year flood level or removed from the floodplain (NWF 1998; FEMA 2010). Through its supplementary mitigation insurance provisions, the NFIP assists compliance with legislation by providing supplementary payouts. This enables rebuilding activities to comply with current building code standards. Eligible expenditure includes the cost of elevating, demolishing, flood proofing or relocating substantially damaged buildings (IFMRC 1994; Wright 2000). According to Wright, writing in 2000, the program had bought and removed an estimated 20,000 structures since its inception (Wright 2000).

Cost benefit analysis following the 1993 floods found that voluntary buyout was most feasible for repetitively damaged properties with a history of high insurance payouts (NWF 1998). Analyses of avoided flood damages indicate that US investment in preventative measures such as relocation have saved considerable amounts of money. In the Upper Mississippi, the 1993 flood caused US$20 billion in damages. Following this, $150 million was spent on relocation as part of the recovery effort. In 2008, a similar sized flood occurred in the same area but the later flood had a much lower damages bill of $2 billion partly because the vacated land was available for flood storage (Freitag *et al*. 2009: 5-6).

The failure of hundreds of flood levees during the 1993 Upper Mississippi floods was a significant factor that triggered the shift in policy towards relocation; while federal USACE flood levees generally performed to design standards, the consequence of over-relying on levees became evident (Wright 2000). While levees can reduce flood frequency, US levee reviews demonstrate that they also encourage additional development (and potential damages) in the areas 'protected'. Inadequate building standards, excessively high levees and lack of preparedness mean damages can be catastrophic if they breach or overtop (ILPRC 2006; ASFPM 2007; Galloway *et al.* 2007; Freitag *et al.* 2009; NCLS 2009; Wenger *et al*. 2013).

Since the 2010–11 floods, the Australian insurance industry has successfully lobbied government to increase investment in structural mitigation such as levees to reduce the frequency of damages (Milliard 2012; Suncorp 2012; Gillard 2013*b*). While levees may be appropriate in some instances, overseas experience suggests that Australia would do well to consider options such as relocation that are more effective, reliable and permanent.

3. Ecosystem Approaches to Flooding

Ecosystem approaches to flooding are increasingly used in countries such as China, the Netherlands, the USA and the UK. These approaches often rely on the strategic relocation of incompatible development. They are characterised by vegetation management, 'room for river' measures that allow water more room to spread, and integrated, catchment-scale planning and management.

'Room for the river' is an approach that was developed in the Netherlands following a series of major floods in the 1990s. While dykes did not overtop or breach, they almost did, and the floods caused widespread evacuations and property damage. This reinforced the high consequence of failure and the limitations of relying too heavily on dykes (Deltacommissie 2008; Dutch Government 2000; 2006; 2012).

In the room for the river program, floodwaters are allowed to spread over a wider area, reducing flood depth. This not only improves safety but means that dykes do not have to be raised higher. The Dutch achieve this by a number of means. Dykes are set back further from the river bank, the meanders of artificially straightened river channels are restored, secondary water channels are excavated and river beds, groynes and floodplains are lowered. For some polders (areas enclosed by dykes), partial lowering of dykes enables water to flow through polders when water levels are high. Development in these poldered areas is still permitted but is relocated to mounds outside the flow path. This approach has been implemented nationally along Dutch rivers, including on the Rhine, the Meuse, the Waal and the Regge (De Boer and Bressers 2011*a*; De Hartog 2012; Dutch Government, nd; Dutch Government 2012). Similar national room for river policies have been adopted in other countries, including in Britain and China (DEFRA 2005; Pittock and Xu 2011).

In the USA, influential proponents of ecosystems approaches include the Association of State Floodplain Managers and the Federal Emergency Management Agency (ASFPM 2007; 2008; Freitag *et al*. 2009; FEMA 2011). Funding, with the dual aims of increasing community safety and restoring flood storage, is available through pre-and post- disaster voluntary acquisition and relocation programs (FEMA 2010). The United States Army Corps of Engineers (USACE) is primarily involved in structural mitigation, but it also recognises the considerable benefits of incorporating greater floodable area into its levee systems. The Mississippi River and Tributaries project, for example, incorporates approximately two million acres of floodways and backwaters into its management options. When activated, these divert excess flows and relieve pressure on levees. The floodways are part of a highly engineered system but they provide much greater flexibility than the 'levees only' policy that was in place up until 1927. When the extent of the

1927 Mississippi flood was compared with the similar-sized 2011 flood, it was found that the use of floodways had reduced flood extent by 62% (Mississippi River Commission 2011).

Releasing floodwaters from the strict confines of mainstem levees has other benefits. When Mississippi floodways were opened in 2011 they deposited much needed sediment on degraded coastal marshes. The marshes form a natural defence against storm surge for New Orleans but confinement of sediment between narrow levees has prevented deposition, contributing to the loss of 3,700 km2 of coastline (Aldous and Jabr 2011; Solomon 2011). Other USA examples of ecosystem approaches to flood management often involve the purchase of land or easements (e.g., covenants on land use) and offer significant side benefits for water quality, fisheries, wildlife and tourism. In one example, marginal agricultural returns made it more economically feasible for farmers to dissolve a levee district and sell the land for wetland reserve than to continue to maintain the levee system (Freitag *et al*. 2009; Kousky *et al*. 2011).

In China, land reclamation was a key strategy for grain production, particularly from 1950 to the late 1970s. As a result lakes and wetlands were cut off from the Yangtze River and polders were constructed in and around lakes. At least 1,100 lakes in the middle and lower reaches of the Yangtze River have disappeared, while Dongting Lake, a major flood retention area in the middle reaches of the Yangtze, has reduced to a third of its original size, from 6,300 km2 in 1825 to less than 2,000 km2 in 2000. Nearby Jianhan Plain has lost 80% of its wetlands to agriculture since 1840. Compounding this problem, extensive deforestation in the upper catchment has increased sediment loads. Silt deposition raises river beds and fills lakes and dam reservoirs, contributing to about 30% of flood storage losses. Overall, it is estimated that land reclamation and siltation have reduced the landscape's water holding capacity by 75 per cent (Guangchun Lei, pers. comm.[32]; Yin and Li 2001; CCICED 2004; Zhang 2004; An *et al*. 2007; Yu *et al*. 2009).

Devastating floods in 1998 triggered widespread support for ecosystem solutions, and existing laws and policies were revised and more rigorously enforced.[33] These supported revegetation and improved soil management of upper catchments, while in the middle and lower reaches polders were removed and sluice gates were seasonally opened to reconnect floodplain wetlands to the river (Zhang 2004; Yu *et al*. 2009; Te Boekhorst *et al*. 2010; Pittock and Xu 2011). This has involved large scale relocation of floodplain populations. During the 1998 floods, 2000 polders breached. During post-flood reconstruction between 1998 and 2003, 1,461 polders

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[33] Key laws include the *Water Law (1988)* which was revised in 2002 to incorporate integrated water resource management; the *Law of Soil and Water Conservation (1991)*, and the *Law of Flood Control (1997)*. The latter already prohibited reclamation of land in wetlands and watercourses and supported planned resettlement. Following the floods these laws were reinforced and supplemented by the 1998 '32 Character Policy', and at the same time a National Logging Ban was imposed.

were demolished and 2.42 million people were relocated to higher ground. These measures resulted in 2,900 km^2 of land being returned to lakes and rivers, increasing flood storage capacity by 13 billion m^3 (Cheng 2004).

China and the Netherlands have both found that for relocation to be successful, it needs to benefit the people being relocated. Regardless of whether acquisition is voluntary or compulsory, this reduces resistance and legal opposition and hastens purchase processes. Demonstration projects in China provided those relocated with alternative livelihoods, increased incomes, improved water quality, health, housing, and clean energy from biogas, as well as reduced flood risk. These outcomes led to broad support from provincial and local governments and uptake elsewhere (Yu *et al*. 2009; Te Boekhorst *et al*. 2010; Pittock and Xu 2011). In the Netherlands, similar 'win-win' outcomes are sought, and a multifunction approach to land use has also resulted in stimulation of local economies and amenity. This cross-sectoral approach is supported by integrated water resource management and basin scale planning (EU 2000; CCICED 2004; De Boer and Bressers 2011*a*; Nijssen 2012; Dutch Government, nd).

Ecosystem approaches have been introduced not only in response to recent large floods, but specifically to address future climate change (Dutch Government 2000; P.R.C. 2007). Climate change is expected not only to increase severe flooding but also drought, while higher temperatures may exacerbate water quality problems. Ecosystem approaches to flooding help to address these issues. They increase flexibility in the system, soaking up water when it is in oversupply, filtering and releasing it slowly. Retaining water for longer increases groundwater infiltration, and improves water availability during drought. The replenishment of groundwater also helps form a barrier to prevent saltwater intrusion in coastal areas affected by sea level rise. Meanwhile, vegetation restoration not only reduces erosion and sediment load but can moderate water temperature and algal growth by providing shade. Rather than putting additional pressure on threatened riparian habitats, ecosystem approaches help ensure their survival. This is a flexible approach that incorporates greater redundancy into the system and improves water security.

Examples of ecosystem approaches in Australia are isolated and localised. They include wetland restoration at Leeton, NSW (Wenger *et al*. 2013) and an award-winning wetland reconnection program near Grafton, NSW (Clarence Valley Council 2013*a*). These projects yielded multiple economic, social and wildlife benefits. Other innovative proposals have been less successful. A Moreton Bay payment for ecological services proposal to reduce sediment loads through vegetation management has so far failed to gain political support, despite being self-funding (QCC 2012), and a proposal to set back levees in the Lower Goulburn floodplain in Victoria failed as a result of opposition to land acquisition and withdrawal of federal funding (Pittock, pers.

comm.[34]; Water Technology Pty Ltd 2005). Nevertheless there has been recent interest in such measures (Rutherfurd *et al*. 2007; Parliament of Victoria 2012; Queensland Government 2012*a*).

4. Relocation policies in Australia

Relocation can either involve rebuilding elsewhere or moving an existing structure to higher ground.[35] As illustrated above, relocation can effectively eliminate risks for those exposed to frequent flooding and enable land to be used for flood storage. Thus relocation and modified land use feature highly in overseas 'room for the river' flood policies. However, relocation has many drawbacks, the most significant for government being the high cost of buying back land. Another problem is that despite repeated flooding and purchase offers, relocation is often resisted by residents. Notwithstanding emotional attachment to place, flood free land can be too expensive compared with the buyback amounts offered for the flood-prone property, or unattractive if the relocation site is too remote (Wenger *et al.* 2013). Relocation has been used numerous times in Australia's history and the towns of Bega,[36] Nowra, Gundagai, Clermont and Smithfield (now a suburb of Cairns) all owe their present locations to catastrophic flooding (Coates 2011). Figure 4.2 is a map of eastern Australia showing the locations of Australian places referred to in this section.

Recent reviews following Australia's 2010-11 floods offer several examples of relocation, including the town of Grantham in Queensland and the Lower Loddon (an agricultural area in Victoria). Queensland's capital city of Brisbane also has a voluntary purchase scheme that was noted in flood reviews. In all these cases, relocation was implemented by voluntary means, either through buyback, land swap or through compensation for rezoning or establishing covenants on land.

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[35] Note that in the USA there is generally a distinction made between 'voluntary acquisition' and 'relocation', the latter referring to lifting an existing structure off its foundations and moving it to a new site. However, in this paper relocation is a more inclusive term whereby assistance is given to help people resettle out of floodplains using various strategies.

[36] For Australian places and associated waterways referred to in this section, GPS coordinates are provided in Table 4.4.

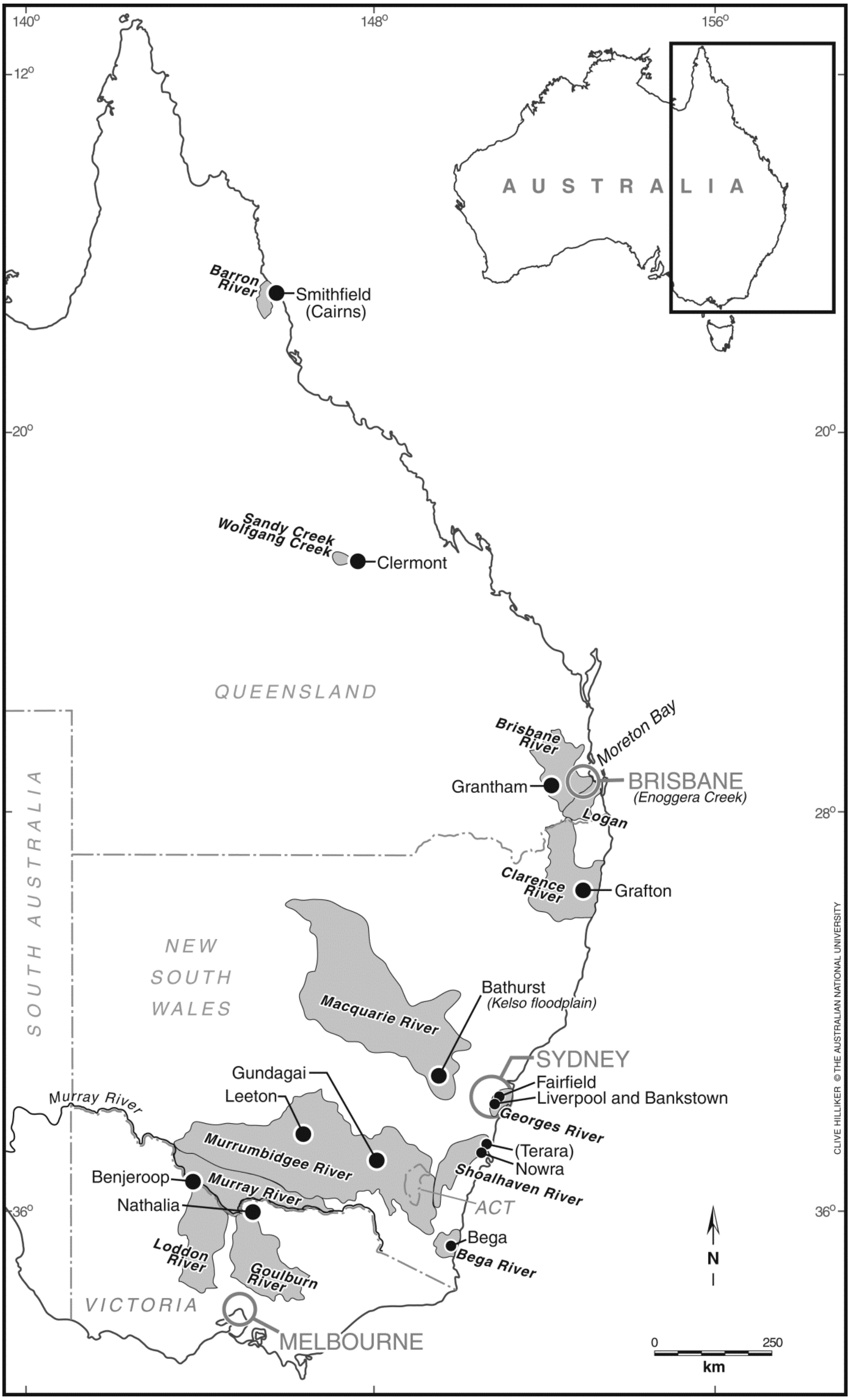

Figure 4.2: Map of eastern Australia showing the location of Australian places mentioned in the text and their river basins.

4.1 Brisbane

Brisbane is one of Australia's most flood prone cities and was badly affected by the 2010–11 floods, with 22,696 residential properties partially or wholly inundated, primarily in the older part of the city. Since 2006 Brisbane has had a Voluntary House Purchase Scheme targeting properties that are most frequently flooded (2 year average recurrence interval) and 525 properties have been identified in this category. However Queensland does not have a state-wide policy for purchasing or relocating flood prone properties and the program is wholly funded by local government (QFCI 2012). According to a review undertaken by the Brisbane City Council following the 2010-11 floods, the uptake of the scheme by Brisbane residents was only modest, though the reasons for this were not examined (Arnison *et al*. 2011). The terms of the scheme offer pre-flood property values. However even where a fair market value is offered this may be insufficient to purchase similar property elsewhere, particularly as flood prone land is often less valuable and residents poorer. Moreover, Brisbane home owners are expected to pay all costs associated with the sale such as conveyancing, transfer costs and stamp duty. Interest in the Brisbane scheme rose following the 2010–11 floods and in the following year the Council doubled the program budget to A$10 million per year to meet demand; 46 properties were purchased between 2006 and May 2011, this figure growing to 73 by September 2012 (Brisbane City Council 2011; Feeney 2012). This represents close to 14% of targeted properties over 6 years.

4.2 Grantham

Relocation of entire communities is less common but can be feasible for small towns, such as Grantham. In January 2011, floods in the Lockyer Valley claimed 19 lives, including 12 at Grantham. Throughout Lockyer Valley, 10 properties were completely destroyed, 19 were beyond repair and 119 properties were severely damaged. To help the community recover and to prevent recurrence the town was relocated to higher ground through voluntary land swap. The project was planned and organised by the Local Council. The Queensland Reconstruction Authority[37] amended planning provisions to ensure the project could be fast-tracked (QRA 2011*c*; Queensland Government 2012*c*).

Land swap is not a measure that will be universally applicable as it depends on the availability of nearby undeveloped and unconstrained land and the Local Government's financial resources (QFCI 2012). However, land swap has some significant advantages over buyout. It can be

[37] An agency established for a limited 2-year term in February 2011 (since extended) to coordinate and manage Queensland's recovery from the 2010–11 floods. Under the *Queensland Reconstruction Authority Act 2011* it was given strong development powers including the right to compulsorily acquire land.

cheaper for councils to afford and it means that people remain in the community. It is also equitable as it doesn't discriminate on the basis of land values (Simmonds, pers. comm.).

Project costs included A$7.5 million paid by the Local Government for acquiring nearby flood free land and $18 million contributed by the State and Federal Governments for infrastructure and service development. A further $30–40 million is expected to be invested in community infrastructure by the council over a number of years (Gillard 2011*a*; Lockyer Valley Regional Council 2011; van den Honert 2013).

Land swap participants were provided with ample assistance. Stamp duty was waived and legal firms provided conveyancing and other legal costs *pro bono*. Those owning investment properties were granted capital gains tax roll-over relief by the Australian Tax Office[38] (Simmonds, pers. comm.). Participants were responsible for the cost of demolishing damaged structures on their old sites and construction on their new sites. However, $2.835 million was made available through a state-wide donations appeal to help people with these costs (Queensland Government 2012*c*). Within two years, approximately 85% of Grantham residents had moved into their new homes (Australian Government 2011*b*; Lockyer Valley Regional Council 2011; van den Honert 2013). Of the 120 new residential sites, all were fully subscribed two and a half years after the disaster, though some transactions were still being finalised (Simmonds, pers. comm.). Vacated flood zone land becomes the property of the Lockyer Valley Regional Council, to be used for parklands, community market gardens and farming (QRA 2011*c*).

Following the relocation of Grantham, a second large flood occurred in February 2013. In the Grantham area, this caused only $20,000 worth of damages to 3 properties. An estimated $30 million was saved in avoided damages (Lockyer Valley Regional Council 2013).

The scale of the disaster and financial assistance available contributed to the success of the Grantham scheme. However it was also due to several other factors, one of the most important being speed. This required strong local leadership as the project had to proceed without funding certainty. The disaster took place in January; the new site had been purchased and infrastructure construction begun by April; the first land ballot took place in August; and the first family moved in by November. This meant people were able to invest their insurance and assistance money into relocation instead of rebuilding or repairing damaged property. Council lobbying eventually led to funding support. Another important factor was that the scheme was

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[38] Land value for a standard block dropped from approximately $100,000 to $20,000 post-flood. Investors wanting to swap their property with a new block worth $120,000 would therefore have incurred significant capital gains liabilities.

voluntary which avoided opposition. The only restriction that applied to rebuilding on the same site was that where a house was destroyed, floor height needed to be raised. Existing planning scheme provisions that regulated building height were broadened to take account of the area inundated and water depth (Simmonds, pers. comm.).

4.3 Lower Loddon

Following the 2010-11 floods in Victoria, the State Government implemented a buyback scheme, the Lower Loddon Irrigators Recovery Package, to irrigators in the Lower Loddon. The primary aim of the scheme was to convert the land from irrigated uses (broad acre and dairy) to more flood resistant rain-fed farming systems. The land most at risk of flooding was first determined by identifying the boundaries of the floodplain. Participating farmers were offered two options. They could either sell their irrigated land at pre-flood values (to be subsequently resold as a rain-fed farm to recoup some of the program costs). Alternatively they could remain on their land and receive compensation to place a covenant on the title of their land, restricting its use to rain-fed practices. Compensation was calculated as a percentage of the pre-flood land value. A$12.3 million was allocated to the package. Flood affected dwellings with minimal residual value were to be demolished, some relocated and some protected individually by ring levees (DSE 2011; Rural Finance 2012).

One of the most notable elements of the Lower Loddon program was its funding arrangements, as it opportunistically piggybacked onto a modernisation of irrigation infrastructure initiative. This scheme aimed to reduce over-allocated water in the Murray Darling Basin as part of the Murray Darling Basin Plan. Contraction of the area of irrigated land and its conversion from vulnerable irrigated to flood-resistant rain-fed uses were thus mutually supportive. This provided an additional source of funding to help people to relocate. The program was successful in being able to purchase all but two properties in the area identified as having the greatest risk (2,751 ha), partly attributable to above market value purchase offers (DSE 2011; McBeath 2011; Rural Finance 2012).

4.4 New South Wales

In recent decades, NSW is the State that has most actively pursued voluntary purchase, and state funding is currently available to local governments for high hazard areas on a 2:1 basis at market value. While voluntary purchase is initiated by individual councils, they have financial and policy support from the State Government and schemes are designed with reference to the NSW Government Floodplain Development Manual. Risk to life is central to hazard rating and numerous factors are considered, including catchment characteristics, ease of evacuation, potential flood velocity, depth and duration (NSW Government 2005, Appendix L; NSW

Government 2013*c*). Between 1999 and 2007 federal funds contributed to the NSW scheme, with voluntary purchase or house raising accounting for close to 25% of allocations from the Federal Government's Regional Flood Mitigation Program (Australian Government, nd). Comparable figures for Queensland and Victoria were 5% and 2.3% respectively, suggesting significantly lower investment in relocation in these states. [39]

NSW funding for voluntary purchase has declined markedly since 2009. Recent funding mechanisms include the NSW Ministry of Police and Emergency Services natural disaster resilience grants (2009-2011), where 17% of flood-related grants were for voluntary purchase, and the Office of Environment and Heritage floodplain management grants (2011-2013) (NSW Government 2012; NSW Government 2013*b*). In the latter scheme, the only NSW government voluntary purchase related grant in the past two years has been a feasibility study in Harden Shire.

Some noteworthy examples of past NSW voluntary purchase schemes include the Kelso floodplain at Bathurst and the Sydney suburbs of Fairfield, Liverpool and Bankstown (Table 4.3). Voluntary purchase was offered in areas of high risk and house raising[40] for areas of lower risk. In the case of Fairfield, the local council commissioned a floodplain management report in 1990 that identified properties in high risk areas for voluntary purchase. A review in 2010 found that 76 out of 96 properties had been bought and returned to flood resilient open space. In Bathurst, 102 properties located in a floodway were targeted for voluntary purchase following floods in 1986. There was low uptake of the scheme until a second flood in 1990. Of these, around 30 remained to be purchased in 2004. In Bankstown and Liverpool 170 properties were purchased between 1984 and 2004 and 32 remained to be bought or moved. The cost of purchasing the remaining properties was high (A$30 million in 2004 figures), a problem compounded by the withdrawal of federal funding and dramatic property value increases. This led to private sector funding sources being explored and land already purchased was proposed for flood compatible uses such as golf courses and sand mining.

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[39] Some caution is needed in interpreting these figures as an indication of state government support for relocation. Funding amounts provided by the Commonwealth were appropriations, not actual expenditure. Neither did they include relocation projects that state or local governments may have funded independently. Where the purpose of property purchase was to enable structural mitigation works, these figures were omitted from calculations. Some figures incorporated house raising. The Australian Government's Natural Disaster Mitigation Program also ran during this period (2003-2009) but it covered all natural hazards and percentages are harder to determine. However, divisions between states for investment in relocation reflect the same trend.

[40] House raising refers to the elevation of structures so that the floor height is at the 'defined flood level' (usually that of a 1:100 year flood event), plus freeboard, which is commonly between 300–500 mm.

Table 4.3. Uptake of voluntary purchase schemes in Australia.

Location	Number of Properties Targeted	Period	Properties Purchased	Source
Kelso floodplain, Bathurst, NSW	102	1986–2004 (18 years)	72 (70.6%)	(Australian Government, nd) (BTRE 2002) (Bathurst City Council 1995)
Fairfield, Sydney, NSW	96	1990–2010 (20 years)	76 (79.2%)	(Bewsher Consulting Pty Ltd 2010)
Liverpool & Bankstown, Sydney, NSW	202	1984–2004 (20 years)	170 (84.2%)	(Bewsher Consulting Pty Ltd 2004)
Brisbane, QLD	525	2006–2012 (6 years)	73 (13.9%)	(Arnison *et al*. 2011; Feeney 2012)
Grantham, QLD	120*	2011–2013 (2–3 years)	120 (100%)	(Simmonds, pers. comm.)
Lower Loddon, VIC	25	2011–2012 (1 year)	23 (92%)	(Neil McBeath, pers. comm.; Rural Finance 2012)

* 120 new lots were developed for the land swap, available to all eligible property owners in the Lockyer Valley (both residential and vacant blocks). The number of eligible properties is unavailable as this was assessed on application.

Australian relocation examples show that voluntary purchase is expensive and can take decades to achieve. However, people are more amenable to it immediately following a major flood particularly if amounts offered are sufficient to acquire equivalent property elsewhere, as at Grantham and Loddon. Thus timing and adequate funding are both factors in successful relocation. It is noteworthy that many of the suburban examples of flood prone properties are inhabited by people on lower incomes as these properties are more affordable. The Brisbane suburb of Rocklea is semi-industrial, while Fairfield and the Kelso floodplain also have a high proportion of low income earners (BTRE 2002; Sellers and Mooney 2012). It can be a substantial barrier to expect people to pay property transaction costs, demolition and moving costs, as well as having to move to a more expensive property that is less central or lower quality, albeit in a safer location. Simply agreeing to pay market value (even at pre-flood values) may be insufficient to achieve relocation.

Table 4.4. Location of Australian places referred to in the text and their waterways.

Place	GPS coordinates	Significant Waterways
Smithfield, Cairns, Queensland (QLD)	16°49’14.01”S; 145°41’31.06”E	Barron River
Clermont, QLD	22°49’29.20”S; 147°38’25.15”E	Wolfgang Creek, Sandy Creek
Brisbane, QLD	27°28’15.36”S; 153°1’24.61”E	Brisbane River, Enoggera Creek
Grantham, QLD	27°34’45.58”S; 152°11’44.63”E	Lockyer Creek, Rocky Creek, Monkey Waterholes Creek
Moreton Bay, QLD	27°12’21.81”S; 153°15’1.28”E	Logan, Bremer, Lockyer river catchments lead to the bay
Grafton, New South Wales (NSW)	29°41’28.04”S; 152°55’59.52”E	Clarence River
Fairfield, Sydney, NSW	33°52’14.83”S; 150°57’19.76”E	Prospect Creek (tributary of Georges River)
Liverpool & Bankstown, Sydney, NSW	33°55’12.07”S; 150°55’26.86”E	Georges River
Kelso floodplain, Bathurst, NSW	33°25’3.55”S; 149°34’51.71”E	Macquarie River and tributaries
Leeton, NSW	34°33’5.01”S; 146°24’23.95”E	Main Canal (Yanco Irrigation Area), Murrumbidgee River, Fivebough and Tuckerbil Wetlands
Nowra (relocation site); Terara (original site), NSW	34°52’30.62”S; 150°35’44.81”E	Shoalhaven River
Gundagai, NSW	35°3’55.30”S; 148°6’25.90”E	Murrumbidgee River, Morley’s Creek
Bega, NSW	36°40’27.04”S; 149°50’34.50”E	Bega River
Lower Goulburn (near Nathalia), Victoria (VIC)	36°3’23.45”S; 145°12’25.41”E	Goulburn River, Broken Creek, Murray River
Lower Loddon (near Benjeroop), VIC	35°28’35.62”S; 143°48’59.10” E	Loddon River, Murray River, Little Murray River, Murrabit River

5. Discussion

Susceptibility to flood is to some degree unavoidable in Australia as the oldest farming settlements were located on fertile floodplains close to water. Badly located development is often found in the oldest part of town, a legacy of the distant past when there was less information on flooding and development controls were less sophisticated or non-existent. However, reviews following the Australian floods show that irresponsible development decisions are still being made (QFCI 2012; Wenger *et al*. 2013). This reflects a nation-wide failure to adequately address disaster prevention[41] (Wenger 2013). It is easier to prevent than to reverse bad land use decisions. Where relocation is unavoidable, the great dilemma for governments is cost. However, examples in this chapter demonstrate that this has not deterred

[41] Federal funding for flood prevention (not to be confused with post-disaster betterment) is through the National Partnership Agreement on Natural Disaster Resilience which, combined with the smaller National Emergency Management Projects grants scheme, provides approximately A$28.7 million per year. This amount is divided between all natural disaster types in all states and territories.

all flood prone countries from investing in relocation. A number of observations can be made about the examples studied:

1. Countries relocate development for different reasons. In Australia, the primary object is to reduce threat to life of those located in dangerous areas. A secondary reason is to enable the construction of structural forms of flood control. In the Netherlands and China, the aim is to create more flood storage on a catchment scale, ultimately lessening massive actual or potential losses. In the USA, relocation is given impetus by a huge federal liability for the private losses of those participating in the National Flood Insurance Program, as well as disaster relief costs.

2. Relocation spikes immediately after a flood. This partly reflects greater willingness of residents to move following floods. However, it is also the most logical point in time for buy out to occur. It makes no economic sense to wait for money to be invested in rebuilding a property before deciding to buy and demolish it. This suggests that efficient relocation requires processes and funding to be in place as part of disaster recovery.

3. Voluntary purchase is most affordable where property is of low value, is frequently flooded, and has a history of high-cost repetitive damage.

4. In the USA, eligibility criteria for voluntary purchase are based on calculations of cumulative past damage and damage sustained in the most recent event. This makes it easy to incorporate relocation into post-disaster recovery following damage assessment processes. This contrasts with NSW's multi-faceted risk assessment approach which is arguably more tailored to pre-disaster mitigation.

5. Examples in this chapter indicate that for relocation to be successful, it has to benefit those being relocated. This results in less resistance, rapid uptake and positive social and economic outcomes. This is particularly important because flood prone areas are often inhabited by disadvantaged people who are least able to afford moving costs. Purchase offers need to be sufficient to cover all the costs of relocation, e.g., through over-market price offers, waiver of property transfer costs and taxes, charitable appeal funds or supplementary insurance.

6. Many different strategies are used to remove people from harm and to ensure land use is compatible with flood mitigation functions. Not all of them involve purchase, which can be viewed negatively if it prevents compatible development ('land sterilisation') or entails ongoing land management obligations by governments. Some strategies identified in the examples covered in this chapter include: compensation for land use covenants on rural land (e.g., Lower Loddon, Regge River); cost share by multiple agencies where mutual

benefits are identified (e.g., Lower Loddon, Regge River); legislated protection of lakes and wetlands (e.g., China); reservation of first preference rights to purchase land in strategic locations (e.g., Netherlands); land swap to avoid unaffordable buyback costs (e.g., Grantham); land swap to prevent opportunistic purchase price elevation (e.g., Regge River); supplementary mitigation insurance (e.g., USA); 'payment for ecological services' or farming subsidies for compatible land management (e.g., Netherlands, Australia, China); flexible land use plans that facilitate the reversion of land to natural uses (e.g., Netherlands); relocation of existing structures to higher ground (e.g., USA, Australia); voluntary purchase (e.g., Australia, USA, Netherlands); financial penalties for communities that permit rebuilds to pre-flood standards (e.g., USA); and compulsory acquisition, particularly where it is in the national interest (e.g., China, Netherlands).

7. Countries with significant relocation programs have strong national government support (e.g., policies, coordination mechanisms, legislated funding ratios to support betterment, purchase conditions, incentives and penalties).

8. In areas where relocation has been carried out, large cost savings have been calculated following subsequent floods.

9. In Australia, flood mitigation is very much a local concern, which results in a patchwork of different measures and safety standards. This favours locally-implemented structural approaches. Countries with a more nationalised view of flood management find it easier to apply ecosystem approaches (and relocation), which benefit from catchment-scale planning and implementation, coordinated across jurisdictions and sectors.

Flood prevention policies studied in this chapter demonstrate that it is feasible to incorporate flood prevention into post-disaster recovery, and this is the approach taken by many countries around the world. However, countries such as Australia that only rebuild to pre-existing standards will be exposed to repeated large damage costs. These costs are likely to escalate in the future due to climate change, population growth and urbanisation.

Incorporating flood resilience into post-disaster reconstruction can involve improved rebuild standards, house raising and flood proofing, or relocating development to a new site. Of these, relocation can have significant social, economic and ecological co-benefits. It can also buffer the anticipated effects of more severe floods (and droughts) as a consequence of climate change. Use of this strategy is applicable to river basins around the world that are likely be affected by climate change.

The examples studied in this chapter suggest that relocation is easier to achieve in the immediate aftermath of a disaster. Thus policies and funding mechanisms need to be in place to ensure opportunities to improve resilience are not missed.

In the case of Australia, the nine observations above suggest that Australia would benefit from greater federal support for relocation programs, particularly during post-disaster recovery. This could entail adoption of the USA requirement that 15% of disaster relief funds be available for spending on relocation and improved rebuild standards. Similarly, eligibility requirements and financial incentives and penalties, could be used to prevent the perpetuation of bad land planning decisions.

Intervention during disaster recovery has many advantages, and there is potential for governments to collaborate with the insurance industry to reduce costs of voluntary purchase. For example, if insurers paid for the actual damage sustained by the property, governments would only need to pay the balance to enable relocation. The advantage for insurers is the removal of properties that cost the most in claims, and an increase in insurance affordability and availability.

For such a scheme to be effective, assessment needs to be rapid following a disaster and property-level information is needed to determine eligibility for buyout. Eligibility criteria currently used in Australia require detailed flood studies which could prevent rapid assessment. As risk is related to damage, another possibility would be to follow the USA method where damage (including cumulative damage from previous floods) needs to be equal to or greater than fifty per cent of the pre-flood market value of the property. Insurers collect flood information on a property level to set premiums so such information may already exist.

Supplementary mitigation insurance products could be developed to cover the cost of house raising or flood proofing if owners elect to stay, or relocation expenses (demolition, moving costs) if they move. This strategy will not be suitable for all post-disaster buyouts, as for many flood insurance is unavailable or unaffordable. However, extending the role of the insurance industry in this way would benefit insurers, governments and owners alike. As out of pocket expenses are a significant barrier to relocation, state and municipal governments could also consider waiving stamp duty or other property transaction fees. These could be offset by lower flood risk and emergency service liabilities and alternative uses for the vacated space.

Investment in relocation is also needed prior to disasters, particularly for at-risk properties and in strategic areas that would result in significant flood mitigation gains, such as the Lower Goulburn levee setback proposal. In Australia, greater efforts could be made to identify synergies with multiple agency portfolios that could lead to creative ways of funding relocation.

Some relocation programs, such as Grantham and the Regge River, Netherlands, demonstrate that land swap strategies can also improve the affordability of relocation, though this will not be suitable in all cases.

6. Conclusion

Floodplains are the interface between land and river and present a challenge for human occupation. Where development has been built in the wrong place, it is tempting to band-aid it with structural mitigation, and recent Australian floods have seen successful lobbying attempts to increase government expenditure on levees. Political pressure to build levees as a result of more frequent or severe flooding is likely to be a common response that will not be restricted to Australia. However the shortcomings of levees, and the failure of cost-benefit analyses to factor in external costs are well documented.

Many countries around the world now recognize that flood threats are growing due to factors such as increasing populations and climate change, and that existing approaches to managing flood risk will not be sufficient to address future risks. Alternative solutions such as improved rebuild standards, relocation and associated ecosystem approaches are now being implemented in flood prone countries around the world. These methods offer a more permanent and effective way of achieving community resilience to flooding and have added benefits in that they can buffer against future threats to water security, and protect the natural resources on which livelihoods depend. Various means are used to achieve these alternatives, including legislation, funding incentives and disincentives, development and land management controls and market mechanisms. In Australia, measures used tend to be almost exclusively cooperative and exhortative, while overseas more coercive means are included in the policy mix. Another difference is that integrated water resource management is often central to overseas flood management. By contrast, Australian flood management is largely conducted on a local scale and catchment-wide flood management would require significant institutional reform in some Australian states. Australia and other flood prone countries can learn much from past examples of relocation and progressive overseas strategies to ensure their management of flood is adaptive to anticipated changes in future flood threats.

7. Acknowledgement

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Publication 5 preamble

Wenger, C. 2015*b*. Better use and management of levees: reducing flood risk in a changing climate, *Environmental Reviews,* **23**(2): 240-255. doi:10.1139/er-2014-0060.

While **publication 4** looks at reasons that might inhibit the uptake of ecosystem based approaches in Australia, **publication 5** examines why new levee projects are being approved in Australia while other countries are attempting to reduce their reliance on such measures.

The paper presents a detailed examination of levees. The paper aims to be realistic in recognising that structural approaches will be used in the future in response to increased flood risk. Levees are assessed against adaptive and maladaptive criteria to determine if they are truly best characterised as maladaptive. Drawing on lessons from case study countries, the paper also investigates by what means adverse impacts could be minimised.

Publication 5 maps complex institutional factors that influence the uptake of structural approaches using an influence diagram. This uses findings from earlier work, as well as additional research of flood studies and local government documents to understand key players, motivations and processes.

In his work on policy transfer, Rose (2005) explained the importance of understanding the context of both the country of origin and the country to which policy is being transferred. He notes that programs cannot simply be lifted and transferred in their entirety but need adjustment to suit the new context. His used flow diagrams to illustrate program goals, processes, decision-making tools, laws, players and funds. Accordingly, the delivery of flood management programs is examined in two countries: Australia and the Netherlands (the latter building on the in-depth case study in **publication 2**). This makes clear some of the institutional enablers (in the Dutch case) and barriers (in the Australian case) that would need to be overcome in policy transfer.

Publication 5 draws on previous work, providing a synopsis of case studies to establish the historical background, the trends and future challenges for flood management in each country. This context is very important for establishing perceptions of flood problems and solutions. **Publication 3** provides a starting point for understanding Australian institutional arrangements for the delivery of disaster resilience programs at federal and state levels. One of its findings was that resilience programs emphasise improving the quality, standards, coverage and accessibility of flood risk information to enable self-reliance and shared responsibility. **Publication 5** reveals a possible inadvertent consequence of this could be increased levee building, a manifestation of 'hydraulic bureaucracies'. Inspired by the **publication 2** quote about the 'Anglo-Saxon style' *ad hoc* approach to flood safety and its emphasis on individual responsibility, **publication 5** also questions Australia's devolved approach. Australia's program delivery is based on the competitive grants system and often flood studies, assessment and management stop at town boundaries. This contrasts with the more holistic but centralised approach of unitary states, which is arguably better suited to river basin scale implementation.

Better use and management of levees: reducing flood risk in a changing climate

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Abstract

Many nations rely on dykes and levees to mitigate flood risk. However, a myriad of problems have prompted views that levees are ultimately maladaptive and should be used as a measure of last resort. This leads to questions not only about the place of levees in future flood risk management, but also whether anything can be done to reduce their impacts.

A detailed review of flood events from Australia, China, the Netherlands and the USA was used to develop a case study for each country. Case studies present existing levee problems, future flood threats and national strategies to address them. These were used as a basis to analyse the transferability of adaptive flood approaches.

While many countries are attempting to restore floodplain storage, thereby reducing their reliance on levees, others are increasing their investment in levee construction. This review explores factors that affect the transferability of adaptive approaches, including issues such as problem recognition, affordability and program delivery. It was found that countries vary in their ability to recognise levee problems and the level at which decisions are made influences the likelihood of adaptive solutions being adopted.

Analysis suggests that federal systems face particular challenges and their capacity to adopt adaptive approaches may be impaired if institutional barriers are not addressed. Regardless of the overall approach to manage flood risk, the experiences of all case study countries offer some broadly-applicable lessons for improving the use and management of levees, reducing their adverse impacts and improving the integration of natural flood mitigation.

Keywords: adaptation, climate change, floods, levees, policy transfer.

Resumé

De nombreux pays comptent sur les digues et les levées pour atténuer le risque d'inondation. Cependant, une myriade de problèmes a incité la vue que les digues pourrait finalement être inadaptées et devraient seulement être utilisées comme une mesure de dernier recours. Cela conduit à des questions non seulement sur le rôle des digues pour le futur management des risques d'inondation, mais aussi ce que peut être fait pour réduire leurs impacts.

Un examen détaillé de la littérature des crues en Australie, en Chine, aux Pays-Bas et aux Etats-Unis a été utilisé pour développer une étude de cas pour chaque pays. Les études de cas révèlent des problèmes pour les digues existantes, les menaces de futures inondations et les stratégies nationales pour y remédier. Elles ont été utilisées comme base pour analyser la transférabilité des approches adaptatives pour réduire les risques d’inondations.

Il a été constaté que, bien que de nombreux pays tentent de rétablir la plaine inondable de stockage, réduisant ainsi leur dépendance à l'égard des digues, que d'autres augmentent leurs investissements dans la construction de la digue. Cet examen explore les facteurs qui influencent la transférabilité des approches adaptatives, y compris des questions telles que la reconnaissance du problème, l'accessibilité et la prestation du programme. Il a été constaté que les pays varient dans leur capacité à reconnaître le problème des digues et que le niveau auquel les décisions sont prises impacte sur la probabilité que les solutions adaptées soient adoptées.

L'analyse suggère que les systèmes fédéraux confrontés à des défis particuliers et leur capacité à adopter des approches adaptatives peuvent être compromis par des obstacles institutionnels s’ils ne sont pas pris en compte. Indépendamment de l'approche globale de gestion des risques d'inondation, les expériences tirées de tous les pays étudiés offrent des leçons largement applicables pour améliorer l'utilisation et la gestion des digues, la réduction de leurs impacts négatifs et l'amélioration des mesures naturelles pour atténuer les crues.

Mots-clés: adaptation, changement climatique, digues, inondations, transfert de politiques.

1. Introduction

Floodplains are one of the most valuable land types for human occupation, but systematic encroachment has degraded them, causing the decline of water quality, biodiversity and soil health on a global scale. River regulation, including water diversion, drainage, impoundment and levee building, interferes with natural flow regimes and prevents the interaction of rivers with their floodplains, constituting a serious global threat to riparian ecosystems (MEA 2005; Tockner *et al.* 2008). Population growth will magnify these problems, as more floodplain land is converted to agricultural use and urban development.

As well as degrading natural resources, floodplain encroachment increases flood risk. More assets are exposed to flood hazards, while land clearance, wetland destruction and urbanisation reduce the landscape's natural ability to absorb water and attenuate floods. This causes faster runoff, deeper floodwater, more rapid flood peaks and higher velocity (Jones 2000; Rutherfurd *et al*. 2007; Tockner *et al*. 2008; Zhou *et al*. 2013). Risks are exacerbated by climate change, which is expected to increase the scale and frequency of flooding in most of the world's major river basins (Hirabayashi *et al*. 2013; IPCC 2013). This will put pressure on human settlements and associated infrastructure built to accommodate historic patterns of rainfall. Flood defences may be overcome more frequently and sewerage and drainage systems may be inadequate, with those already disadvantaged expected to experience the highest increase in risks (Galloway 2009; Jha *et al*. 2012). This will put great pressure on flood management systems, making it imperative to plan for and implement adaptation measures.

Despite perverse incentives such as government disaster relief funding, frequent exposure to severe flooding is likely to increase investment in flood mitigation (Newell and Wasson 2002; Neumayer *et al*. 2014). Mitigation is commonly divided into structural, non-structural and ecosystems based approaches. Structural mitigation includes measures such as dykes, levees, dams and drainage channels that are intended to control which areas flood. Non-structural approaches, recognised since the 1940s, tend to be directed towards human behaviour and management of floods. They include land use and building controls, risk awareness, flood warning, emergency management (EM) and insurance (White 1945; Wright 2000). More recently, ecosystems based approaches have been used to enhance the landscape's natural ability to absorb and store floods through features such as wetlands and vegetation. This approach better supports the need to maintain connectivity between rivers and floodplains and can minimise the cumulative effects of anthropogenic activity (Freitag *et al*. 2009; Jones *et al*. 2012; Lapointe *et al*. 2014).

Flood levees have a long history of use in many countries and continue to be popular. This can be attributed to many factors. For communities at risk, having a visible barrier to keep water out provides the impression of security and tangible evidence of 'protection'. Furthermore, the financial cost of levee construction is usually fully or partially externalised to wider society because the investment required is often beyond the means of local communities. This can greatly increase the appeal of structural mitigation works to those affected; by contrast measures such as house raising and flood proofing are more likely to be borne by individual home owners (Smith 1998).

Levees are also popular with policymakers as they are regarded as being the most cost-effective mitigation measure for existing development, or the only real option available (SCARM 2000; UNFCCC 2006; The World Bank 2010; Liao 2014). Thus although non-structural approaches will be included in the mix of measures used, increasing exposure to floods, rising damages and political pressure are likely to lead to increased levee construction and reinforcement.

Given the interruption of natural flow regimes is among the most serious global threats to freshwater ecosystems, and that communities face the threat of heightened risks due to larger than design floods, reducing reliance on levees and using them more strategically in the future will continue to be a challenge. This paper seeks to:

- review problems associated with levee use;
- identify solutions and assess whether they have wider application; and
- make recommendations that would result in the better use and management of levees.

2. Methodology and theoretical background

This paper builds on earlier work that assessed a broad array of adaptation measures to address future flood threats. During the course of this assessment, the use and management of levees emerged as an issue of particular concern warranting further attention (Wenger *et al*. 2013).

Research was based on a detailed literature review of four flood-prone countries: the Netherlands, China, the USA, and Australia. Sources included (though were not confined to) flood reviews, government documents and academic literature. Case studies were developed for each country and were verified for accuracy by national experts. The case studies outline the history of levee use and current issues to describe problems that can emerge when using levees as a mitigation method. As the prospect of greatly increased future flood damages is common to all countries, case studies also examine the ways in which each country is addressing future threats, with a particular focus on the relative importance of levees and innovative methods of managing them.

Flood management approaches were assessed for adaptability to future challenges and uncertainties. Adaptive characteristics considered in this article include flexibility, reversibility, synergies, low cost and 'no regrets' strategies and soft management approaches (Hallegatte 2009). Successful adaptation also depends on long term planning, the use of broad spatial scales and factors such as social equity and acceptability (Adger *et al.* 2005), which were also taken into account. Least adaptive approaches were identified using Barnett and O'Neill's (2010) characterisation of maladaptation.

Adaptation literature often presents levees as a 'bad' hard engineering response, not only because of their many unintended side-effects but also because incremental changes can enable the continuation of 'business as usual' and inhibit the implementation of more transformational options (Kundzewicz *et al*. 2007; IPCC 2012). However, there is a distinct lack of literature about how to reduce reliance on levees. This reflects a general focus on the desirable ends of adaptation policy as opposed to means through use of policy and institutional structures and processes (Dovers and Hezri 2010).

While current literature relating to flood infrastructure focuses on countries heavily dependent on levees, little attention is given to countries such as Australia where levee problems are less apparent and how to prevent them repeating mistakes found elsewhere. Comparative public policy offers insight into the practicalities of implementing adaptive approaches, and opportunities for policy transfer. Transfer between countries can be challenging: according to Rose (2005), programs are subject to inertia as it requires effort to proactively search for optimal alternatives when nothing is apparently wrong with what is already in place. However, maintaining the *status quo* is no longer an option when programs fail to achieve their objectives, causing 'dissatisfaction' (in the current example, dissatisfaction is indicated by the need for flood reviews). This equates to the reorganisation phase of the adaptive cycle, which provides a policy reform window (Gunderson and Holling 2002; Meijerink and Huitema 2010). While common problems occur in many different countries, solutions can vary, providing a variety of potential solutions that have the advantage of already being in use and 'proven' to be effective in that setting (or conversely, they provide lessons of how *not* to do it if ineffective). The challenge is to transfer desirable programs to a new setting where values, norms, institutional structures and resources may be different (Rose 2005; Briscoe 2014).

This paper investigates factors that may influence transferability through analysis of case studies. This means looking not only at programs but also at decision-making processes within programs, the adaptive capacity of institutions, and at various institutional influences, including interest groups, information, rules and organizational structures that affect the selection of measures (Dovers 2005; Ostrom and Cox 2010).

Examination of the part played by scales of governance in the decision-making process was a key consideration. Lal *et al*. (2012) note that while there is a trend towards decentralising disaster management to sub-national and local levels of government, there has been little research into the effectiveness of this strategy. To help address this, the paper supplies a detailed, empirical cross-jurisdictional analysis of policy options for adaption, and their effectiveness in the context of flood management (for further discussion on assessing adaption measures see section 4.1).

Analysis used process diagrams to illustrate program delivery and an influence diagram to help identify linkages, incentives and players in the decision-making process (Newell and Wasson 2002; Rose 2005).

3. Comparative case studies

3.1 The Netherlands

3.1.1 History of levee use and issues

Dykes have been used in the Netherlands for flood protection and land reclamation since the thirteenth century. As soil dried and peat decomposed, dykes were raised higher to retain increasing volumes of water. Meanwhile, development behind dykes increased, leading to ever increasing consequences should defences fail (Hallie and Jorissen 1997; Dutch Government 2012).

Over the centuries, the Dutch developed highly sophisticated water management systems in the form of dykes, sluices and drainage canals, and through management and funding mechanisms to maintain them. Dutch Water Boards were formed to regulate and maintain flood defences, and more recently, to ensure water quality (Lazaroms and Poos 2004). Flood management in the Netherlands became increasingly centralised following the formation of the national Rijkswaterstaat to coordinate water boards in 1798 (Lintsen 2002).

Following catastrophic floods in 1953, which flooded 400,000 hectares of land and killed 1,800 people, the Dutch embarked on an ambitious Delta Works program. The program was a structural works program which raised dykes and built flood surge barriers and closure dams across the mouths of coastal inlets. Despite major investment in structural works, the Netherlands again experienced a series of severe floods in 1993, 1995 and 1998. Thousands of homes outside dykes were flooded and dykes only just held. This resulted in a strong consensus that flood threats needed to be addressed (Bezuyen *et al.* 1998). Criticism of the structural approach has mounted since the 1960s, particularly by environmentalists concerned about impacts on ecosystems, including removal of vegetation, river straightening, loss of wetland connectivity, increased susceptibility to drought and poor water quality (Huitema 2002; De Boer and Bressers 2011*a*).

3.1.2 Future flood threats and response

The Netherlands is highly vulnerable to climate change due to sea level rise and increased river flows from ice melt, while growth in population and rising wealth are expected to increase future risk. Despite having a history of tight structural control over water, the Netherlands' current approach centres on a recognition that dykes cannot be raised continually higher or the consequences of failure will mount (Dutch Government 2000; Deltacommissie 2008).

Dyke reinforcement continues to be a primary measure to combat future risks. However, a policy shift has occurred towards 'room for the river' strategies that aim to restore floodplains and spread floodwaters over a wider area, reducing their depth. Added benefits of holding water on designated flood retention areas include groundwater replenishment and reduced seawater intrusion, useful adaptations for climate change-related drought and sea level rise. Such projects are now widespread, and are found on all major Dutch rivers including the Rhine, Meuse, Waal and smaller rivers such as the Regge (Dutch Government, nd; Dutch Government 2006; De Boer and Bressers 2011*a*; De Hartog 2012).

River widening projects often involve relocation of people and/or changes in land use. In a country as densely populated as the Netherlands, returning land to rivers is challenging as space is at a premium. Projects are therefore integrated to achieve multiple benefits for all stakeholders (for insight into implementation, see the review of Regge River projects by De Boer and Bressers 2011*a*). This approach is not without problems however, and regional plans often water down ecological objectives (Dieperinka *et al.* 2012).

Dutch flood policies are formulated nationally and are supported by legislation and quarantined funding (Dutch Government 2006; Van Alphen 2013). While it is willing to enforce unpopular decisions in the national interest, the government simultaneously provides the flexibility for decisions to be implemented locally in ways that are most acceptable, as in the case of Nijmegen (Nijssen 2012).

3.2 China

3.2.1 History of levee use and issues

China's history of land reclamation spans two thousand years. Levees can be as high as 37 metres and have massive consequences if they fail (Yin and Li 2001; Zhang 2006; Zhang *et al.* 2006; An *et al.* 2007; Pittock and Xu 2011). Levee protection alone is generally insufficient to accommodate major floods. For example, Wuhan, one of the most frequently flooded cities along the Yangtze River, has 800km of levees but they only provide flood protection up to the 20-30 ARI[42] event and larger floods are diverted to detention basins, which are an important element of Chinese flood control. These basins are usually inhabited due to land scarcity (Shen 2010).

In 1998, disastrous floods lasting more than seventy days occurred in the Yangtze River Basin. The floods covered approximately 90,000 km^2 and affected 200 million people, with over 4,000 casualties and an estimated US$20 billion in economic losses (CCICED 2004). This triggered intense public debate and reviews of existing flood control strategies. Agricultural polders (areas enclosed by dykes) built in and around lakes and the isolation of wetlands from the Yangtze River by dykes and dams have drastically reduced the landscape's water holding capacity. Dongting Lake, a major flood retention area in the middle reaches of the Yangtze, has lost 60% of its area to agriculture, with peak losses occurring between 1950 and 1978 (CCICED 2004; Liu *et al.* 2004; An *et al.* 2007). An *et al.* (2007) report that for China as a whole, water storage capacity has reduced by 237km^3 over the past 50 years. Over the same period, the construction of 85,000 reservoirs increased water storage by only 36km^3.

Levees have caused several problems in China. In the middle and lower Yangtze, levee systems extend 45,000 kilometres (Zhang and Wen 2001). They restrict river channel capacity, causing higher flood levels. They also increase siltation of the floodplain and river channels between the levees, a problem compounded by the deforestation and soil erosion of upper catchments. Gaps in the Great Jinjiang Levee release sediment into Dongting Lake, accounting for approximately 30% of the loss of the lake's flood storage capacity (Yin and Li 2001; CCICED 2004).

Human activities such as these have reduced discharge capacity causing flood frequency in the Yangtze to increase. The annual maximum water level, particularly in the middle reaches, is becoming higher and in 1998, flood levels were up to 13m higher than the levee-protected plains in some places (Yin and Li 2001; Wang 2004; Zhang *et al.* 2006). Similar findings have been reported for other Chinese rivers, including the Yellow River in Northern China, where sediment is trapped between levees in the lower reaches, resulting in perched riverbeds, metres above the floodplain (Saito *et al.* 2001; Yu 2002).

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[42] Average Recurrence Interval (ARI) is used to indicate how frequently a flood of a given magnitude can be expected to occur. It expresses the likelihood of occurrence in terms of the long-term average number of years between flood events as large, or larger, than a selected flood event. For example, a 100 year ARI flood will occur *on average* once every 100 years. However, the *actual* number of years between flood events is not regular. Climate change is altering precipitation patterns which means that flood frequency figures based on historic data may become increasingly unreliable. This is known as the loss of climate stationarity.

3.2.2 Future flood threats and response

Climate change is expected to increase interannual variability and the likelihood of extreme weather events. Climate projections suggest that the Yellow River Basin in northern China is likely to experience a decline in precipitation, while winter precipitation in the southern Yangtze River Basin will increase. These trends are already being experienced (CCICED 2004; P.R.C. 2007). This will exacerbate the effects of unsustainable land and water use practices and flood defences are likely to be overcome more frequently (P.R.C. 2007; Yu *et al.* 2009).

The magnitude of the 1998 Yangtze floods and concern about increasing flood frequency led to reassessment of existing flood control strategies and reforms through the '32 Character Policy'. While structural measures continue to dominate, improved land management and water storage capacity have become key strategies to mitigate floods. This is achieved through revegetation of upper catchments, polder removal, floodplain and wetland restoration, dredging, dyke management, and relocation as part of post-disaster reconstruction. Such measures resulted in 2,900km^2 of land being returned to lakes and rivers between 1998-2003, increasing flood storage capacity by 13 billion m^3 (Cheng 2004).

The 32 Character Policy was followed by an amendment to China's Water Law in 2002 incorporating integrated river basin management (CCICED 2004; te Boekhorst *et al.* 2010; He 2013). Implementation has included the use of demonstration sites to restore connectivity to a number of lakes that had been cut off from the Yangtze by dams and dykes. Project design ensured local communities benefited from changes in floodplain management through transition subsidies, development of alternative livelihoods, improved water quality and the recovery of fish stocks (Yu *et al.* 2009; te Boekhorst *et al.* 2010; Pittock and Xu 2011). The government is continuing to invest in wetland restoration and aims to achieve protection for 90% of natural wetlands by 2030 (An *et al.* 2007; CCICED 2010).

3.3 USA

3.3.1 History of levee use and issues

From 1866 until catastrophic levee failures in the Mississippi floods of 1927, America embraced a 'levee only' policy that excluded alternative options (Wright 2000). While floodways were later incorporated, levees have continued to dominate, partly due to the provisions of the National Flood Insurance Program (NFIP), which allow land protected by an accredited levee to be exempt from flood planning regulations and insurance requirements (Galloway *et al*. 2006; ILPRC 2006; Mississippi River Commission 2011).

Defining flood events in recent years include the 1993 mid-west flood and the flooding of New Orleans in 2005. The mid-west flood resulted in unprecedented losses of US$18.1 billion and 52 deaths, while the New Orleans disaster resulted in yet greater losses, totalling $200 billion, and claimed 1,800 lives. Levee failure was a factor in both disasters, and is involved in a third of flood disasters (Chagnon 2000; ILPRC 2006; NCLS 2009).

These flood events led to a major reassessment of the role of levees in flood management, and a series of reviews into the management and performance of levees by states and federal bodies. Reviews found that one of the reasons for the high degree of damages was misplaced faith in levees. Perceptions of 'safety' provided by levees lowers public awareness of risks, not only endangering lives but facilitating the ongoing development of flood prone land. Levees also prolong flooding by impeding drainage. Many reviews suggest that levees built to 1:100 ARI are inadequate, especially for urban areas. Some reviews also suggest that levees provide less protection than elevation of structures to the same design height, partly because when a levee fails, assets behind the levee can be completely inundated whereas a house raised to the same level may only receive minor over-floor flooding (ILPRC 2006; ASFPM 2007; Galloway *et al*. 2007; NCLS 2009; NRC 2009).

Levees were also criticised on the grounds of affordability. Levees are associated with high costs, during construction and in perpetuity afterwards. Many were built using out-of-date standards and flood mapping, and have deteriorated due to lack of maintenance. Inspection, certification, maintenance, operation and repair are ongoing, often unaffordable burdens for local communities. These services are also becoming harder to access as levee failure exposes governments and engineering firms to legal liability (ILPRC 2006; Larson 2009; NCLS 2009).

National Economic Development provisions have resulted in projects built to minimum standards as there are no additional economic gains for projects exceeding NFIP requirements. Meanwhile, local contribution requirements introduced in 1986 led to a shift from coordination across watersheds to a focus on individual projects (NCLS, 2009). Public safety and economic security are compromised by inadequate administration and lack of a basin-wide, systems approach to construction standards and maintenance and a lack of oversight (Tobin 1995; ILPRC 2006; NCLS 2009; USACE 2009).

Assessment of external costs during planning was also found to be inadequate. Levees have negative impacts on other floodplain communities, the environment and natural resource dependent industries (Tobin 1995; ASFPM and NAFSMA 2007; Keddy 2007; Freitag *et al*. 2009; Larson 2009). Maintenance requirements, such as vegetation removal, can conflict with wildlife protection legislation (BAFPAA, nd; CSAC, nd; USACE 2006).

3.3.2 Future flood threats and response

Heavy precipitation events are expected to increase in both number and magnitude over most parts of the USA, a trend that is already apparent. River flooding is currently increasing in the northeast and mid-west, although it is decreasing in southern regions. Areas where overall precipitation is expected to reduce may nevertheless experience rainfall events of greater intensity which is likely to lead to flash flooding. Problems are likely to be exacerbated by urbanisation and the continued development of high flood risk areas (ILPRC 2006; ASFPM 2007; Galloway *et al*. 2007; Larson 2009; NCLS 2009; IPCC 2012; Georgakakos *et al*. 2014).

Recent flood disasters, including the 1993 mid-west flood, the New Orleans floods of 2005, and more recently, Hurricane Sandy in 2012, have prompted legislative and policy reforms. Disaster relief provisions have shifted towards preventative recovery in the form of property buyback, relocation and house raising. These are often associated with riparian restoration and socio-economic benefits (NWF 1998; Wright 2000; ASFPM 2008; Freitag *et al*. 2009; FEMA 2010).

Uncertainty about how levees will perform in containing future floods is a significant issue. Recent administrative reforms target levee safety, including improved risk communication and preparedness. Attempts to achieve risk-based flood insurance have so far proved unsuccessful. Resilience strategies have also been introduced which recognise a range of measures, including levees, which can be used to reduce flood risk (NCLS 2009; NRC 2012*b* FEMA 2014).

3.4 Australia

3.4.1 History of levee use and issues

Australia's susceptibility to flooding is largely a legacy of its past, when agricultural pioneers selected floodplain sites for farms and settlements (Smith 1998; Pigram 2007; Coates 2011). Despite modern planning and development instruments, poor siting continues to occur (Comrie 2011; QFCI 2012; Wenger *et al*. 2013).

For much of Australia's history, state and federal support for levee building has been minimal, and while levee funding has been available on a cost-share basis since the 1970s, federal investment in mitigation remains low (Smith 1998; Wenger *et al*. 2013). Nevertheless, there has been significant levees investment in some states. New South Wales implemented a flood mitigation infrastructure program following severe floods in the 1950s. Following the completion of recommended post-1950s works, major flood losses occurred again in the 1970s, revealing the weaknesses of an overly structural approach. Subsequent policies recognised the importance of land use planning (Smith and Handmer 1984).

In 2010-11, the States of Queensland and Victoria experienced unprecedented flood damages, costing governments and insurers approximately A$10 billion, and prompting numerous flood reviews. Reviews identified significant levee management issues. Levees in Queensland were largely unregulated (QFCI 2012), and the State of Victoria identified informational, regulatory, administrative and maintenance deficiencies (DSE 2012*a*; DSE 2012*b*; Parliament of Victoria 2012). Other levee problems included the loss of riparian habitat, lower water quality and more severe catchment-wide flooding (Rutherfurd *et al*. 2007; DSE 2012*a*; Parliament of Victoria 2012). This led the Victorian Department of Sustainability and Environment to cite the lack of management of cumulative impacts of existing and future levees as a key issue (DSE, 2012*a*). There are also examples of levees tempting additional development of floodplains (Atkins and Vince 2009); reducing awareness of need for evacuation planning at Goondiwindi, Queensland (QFCI 2011), and impeding drainage for extended periods (Gannawarra Shire Council 2011).

3.4.2 Future flood threats and response

Floods are expected to worsen in Australia due to climate and population changes (Queensland Government 2011; Steffen *et al.* 2013; Hirabayashi *et al*. 2013). At 1.8 per cent in 2013, Australia's population growth is one of the highest among developed countries, stimulating development of floodplain land, especially in heavily populated coastal fringes (Australian Government 2009; Abel et al. 2011; ABS 2013). Despite this, post 2010-11 flood reviews failed to consider how future threats such as climate change and population growth should be approached and whether current flood management strategies and activities will be sufficient to address them (Wenger *et al*. 2013).

Australia's national strategy for addressing flood threats is to increase resilience (COAG 2011), an approach underscored by shared responsibility and public awareness of risk. There has therefore been considerable effort in recent years to improve the quality and availability of flood risk information. This has included specific measures to address climate change including incorporation of climate change into Australian rainfall and runoff tables (used in development planning) and risk assessments (AGD 2009; QRA 2011*a*; State of Victoria 2011; Australian Government 2012).

The 2010-11 flood events, as well as repeat flooding in the years since, have generated political pressure to build more levees. This has been spurred by the prospect of unavailable or unaffordable flood insurance, as insurers demand that towns build levees or face escalating premiums or the withdrawal of insurance cover (Milliard 2012; State of Victoria 2012*a*; Suncorp 2012; Walsh 2012; Gillard 2013*b*; Queensland Government 2013*a*).

Review outcomes have prompted improvements, including the introduction of levee regulation in Queensland, and better flood mapping and warning (State of Victoria 2012*b*; Queensland Government 2013*b*; State of Queensland 2013). However, standard disaster recovery provisions do nothing to reduce future damages; rebuilds are to pre-existing standards, while examples of relocation are standalone rather than on-going strategies (DSE 2011; LVRC 2011; Wenger 2013). National policy on disaster funding is currently undergoing review, which could impact on future funding availability for levees (Productivity Commission 2014*a*).

3.5 Case study lessons

Case studies reveal numerous problems associated with levee use. However, while approaches to flooding have diversified, most countries have nevertheless incorporated the use of structural approaches into strategies to address future flood threats. Levee use is therefore likely to continue. Where levees are used, case studies offer many lessons about how to improve their safety, administration and environmental performance (see Table 5.1).

Table 5.1: Improving levee use and management: lessons from case studies.

Better management	How	Why this helps
1. Planning		
Levees should be viewed as a last resort[1]	Plan development to avoid the need for future levees. For existing development, favour options that have fewer adverse impacts, e.g., house raising, enhancing natural flood storage, improved building standards for urban renewal.	Minimises adverse impacts of levees.
Catchment-wide planning: flexible, local implementation	Catchment level flood planning to optimise natural mitigation features and integrate land use. Assess the cumulative impacts of flood levees and other structures on floodplain storage[2]. Set limits.	Win-win outcomes for a variety of stakeholders. Minimises adverse impacts of levees such as increased velocity and depth of floods, erosion, siltation and potential damage across the entire catchment.
Cost Benefit Analysis	Assess CBA methodologies for the likelihood of achieving long-term adaptive outcomes. Supplement with qualitative decision-making approaches[3] and IWRM[4].	Improved decision-making
Systems approach	Plan and design all elements of flood mitigation as a system (e.g., drainage, pumps, levees, floodways, wetlands). Ensure systems have clear oversight, roles, responsibilities, accountabilities.	Improved performance and reliability in a flood.
Arrangements for temporary levees	Plan temporary levees to fit into emergency planning frameworks.	Predictable flood behaviour and lower flood risks.
2. Safety		
Manage residual risk	Use development controls to prevent additional development behind levees. Maintain building standards behind levees (e.g., raised floor levels, flood proof materials and design). Encourage flood insurance. Conduct continuous flood risk and response awareness campaigns. Plan for levee failure (e.g., levee design, flood warning systems, evacuation routes, triggers, identify and assist vulnerable people).	Consequences are not increased when levees are breached.

Better management	How	Why this helps
Tolerable Risk Guidelines	Develop policies, standards and best practices relating to levee safety.	Improved levee safety and better understanding of risks.
3. Administration		
Standards for levee design, siting and maintenance	Ensure best practice standards that address structural reliability, contingencies (e.g. spillways, controlled breach plans) and ecological performance. Designing for 1:100 ARI may be inadequate for high population centres or to accommodate future catchment and climate changes.	Increased reliability. Adverse impacts minimised.
State or national levee database for all levees (public and private)	Include: location, height/size; level of levee protection; area/m3 excised from floodplain; ownership and maintenance responsibility; condition; risks associated with levee failure. Location and height/size of levee-like structures need to be included.	Availability of information to determine safety status and management priorities. Useful for emergency response.
Maintenance, Inspection, Reporting, Auditing, Repair	Ensure clear responsibilities; criteria; annual inspections; maintenance scheduling and reporting; periodic audit by regulators; resolution of liability issues; inclusion of information into a levee database. Collect information about post-construction costs, including indirect and legal costs.	Performance of well-maintained levees is predictable: assists response. Better information for decision making.
Financial arrangements	Require contributions from beneficiaries towards levee construction, operation, inspection, maintenance and repair, and to compensate those adversely affected e.g. through local rates. Require proof of long-term technical and financial ability to undertake these commitments prior to levee building. Ensure equivalent financial support is offered for alternative options.	Discourages unnecessary levee building and encourages exploration of alternatives.
4. Regulation		
Permit system	Classify levees as assessable development. Require triple bottom line assessment of direct and indirect impacts across the catchment. Develop provisions to remove illegal levees. Ensure levee approval conditions address negative environmental impacts and	Discourages the construction of unnecessary levees. Minimises adverse impacts. Incorporation of offsets means externalities are

Better management	How	Why this helps
	loss of water holding capacity, e.g., projects required to offset impacts through wetland restoration, improved connectivity, construction of artificial wetlands. Monitor presence of levee-like structures and if potential impact is significant, regulate them.	better factored into project cost.
5. **Environment**		
Levees set back from river banks	New levees need to be set back from the bank. Old levees can be set back or realigned in strategic areas to increase flood plain width.	Gives space to riparian vegetation and fauna that would otherwise be compromised by levees or their maintenance. Provides space for recreation. Wider floodplains allow channels to meander and accommodate more water, reducing velocity and depth. Siltation and erosion reduced; water quality improved. Lower hydraulic load increases levee reliability, reduces repairs.
Connectivity of rivers, tributaries and wetlands	Flexible 'closable open' floodgates that can remain open most of the time and closed only in large floods or storm surges.	Minimises environmental impacts of levees. Wetland restoration can offset loss of flood storage. Improves water quality, industry productivity (e.g., fisheries).

[1] This view is held by many USA flood management experts, including the Association of State Floodplain Managers (ASFPM 2007) and Freitag *et al*. (2009:46-47) who have written a text for the Federal Emergency Management Agency (FEMA) graduate course on flood management. The Dutch Government expresses a similar view when explaining its Room for the River Planning Key Decision (Dutch Government, 2006:7).

[2] For a review of cumulative effects assessment, see Duinker *et al.* (2013).

[3] The Dutch approach is summarised in the Deltacommissie (2008:74). Freitag *et al*. (2009) also promote a qualitative approach.

[4] Integrated Water Resources Management (IWRM) generally refers the holistic management of water resources, integrating the needs of different water-dependent and land use sectors. IWRM takes a basin approach, encompasses the needs of the natural environment and incorporates concepts of sustainable development and equitable use.

4. Discussion

4.1 Adaptive approaches

Case studies reveal that dykes, levees and associated infrastructure are becoming increasingly unreliable while flood threats are escalating. Countries that have relied on structural methods of flood control for centuries are now recognising their limitations and are turning to new approaches to adapt to climate change and reduce flood risks.

Assessment of levees against adaptation and maladaptation criteria (Adger *et al*. 2005; Hallegatte 2009; Barnett and O'Neill 2010), suggests that levees are maladaptive. They reduce the vulnerability of populations protected by them, but only for more frequent, low level flooding; vulnerability to infrequent, major floods increases. When major flooding occurs, the disadvantaged may be worst affected (Tierney 2006; NCLS 2009). Levees are also inflexible, adversely affect other communities and natural resource based sectors, are high cost and introduce path dependency (see Table 5.2).

Table 5.2: Assessment of levees against adaptive (A) and maladaptive (M) characteristics. *Characteristics are derived from Adger (2005), Hallegatte (2009) and Barnett and O'Neill (2010), referenced in the text. Characteristics are not ranked but can be used to identify whether an adaptation option is likely to be adaptive or maladaptive.*

Characteristic	How Levees Perform
'No regrets' (A)	The long-term, adverse impacts of levees are not 'no regrets'. However, in the short-term, where decision-making is dominated by proximate economic criteria, levee construction appears favourable where flood loss is frequent, regardless of increased threats from climate change.
Flexibility/reversibility, robustness to uncertainty, effectiveness (A)	Physical structures are not easily moved or demolished. This applies to both levees and the built assets behind them. Levees are limited by their design height and while they can be upgraded (this can be costly), they do not easily accommodate increases in flood threat as a consequence of climate change or catchment modification.
Cross-sectoral synergies, co-benefits (A)	Levees benefit real estate and construction industries, which has the perverse effect of increasing the amount of assets at risk. Negative impacts are commonly reported for fisheries, tourism and environment sectors.
Soft management approach (A)	Levees are 'hard' physical structures. However siting and design can contribute to softer levee management in the future, better reliability, reduced 'hard' maintenance and fewer negative impacts.
Economic efficiency, including presence of low cost safety margins (A)	It is cheaper to incorporate higher safety standards into original levee design than to retrofit. However, initial and ongoing levee costs are high and often unaffordable for local communities (ILPRC 2006; NCLS 2009).
Long planning scales (A)	Levees and the development they protect remain in place for centuries. However many of those involved in flood management decision-making operate on short term planning scales. Government terms of

Characteristic	How Levees Perform
	office are short. Insurers base premiums on one to five year timeframes (Petherick 2011). Methodologies to assess options may only calculate costs and benefits over a twenty- or thirty-year timeframe.
Broad spatial scales (A)	Flood studies commonly assess the impact of a specific proposed structure on nearby development. However, cumulative impacts of levee building across catchments can be neglected, especially where flood management is a local responsibility.
Socially acceptable; legitimacy (A)	Acceptability depends on many factors such decision-making processes, values, flood experience, cost to local and wider community, perceived equity, and understanding of hydrological processes. This varies according to community.
Equitable (A)	Inequities arise where a town straddles a river and only one bank is protected e.g. in Australia, Wagga Wagga's levees protect the business district, disadvantaging North Wagga residents, who experienced a drop in property values (Wenger et al. 2013). Flood risk increases for unprotected properties due to afflux and insurance premiums may be higher. Inequities also occur between towns within the same government area when one town is given protection and not another (Smith 1998).
Disproportionately burdens the most vulnerable (M)	Levees protecting high value assets are most likely to benefit the affluent. The failure of the New Orleans levees in 2005 disproportionately affected people who were poor, of low status, the elderly and disabled, who had less ability to evacuate and recover (Tierney 2006; NCLS 2009).
Negatively impacts other systems, sectors or social groups (M)	Levees negatively impact other sectors, particularly the environment and natural resource dependent industries. They can increase flood severity for other communities.
High opportunity costs (M)	Levees compromise industries and services that rely on healthy ecosystems.
Reduce incentive to adapt (M)	Levees are associated with regression of building standards and relaxation of development restrictions (Atkins and Vince 2009; Keogh et al. 2011). Adaptation by individuals such as relocation, house raising, flood proofing and insurance is less likely where levees are perceived to address risks. Residual risk is often neglected due to reduced flood awareness and experience.
Path dependency (M)	Levees limit future options. By encouraging additional development of flood-prone land, levees increase the assets at risk (potential damages), thereby increasing 'benefits' of future levees (Smith 2000; Abel et al. 2011).
Increases GHG emissions (M)	Pumping costs are significant in some countries and contribute to GHG depending on power source. Construction, maintenance and repair cause some emissions. Levees contribute to the loss of wetlands (carbon sinks).

If levees are ultimately maladaptive, the challenge is to reduce their use and improve their management. Despite problems, long-term reliance on levees means the Netherlands and China cannot easily abandon this approach. The reinforcement of key levees remains an important strategy to adapt to future threats. However, new approaches implemented in these countries demonstrate that much can be done to improve the water storage capacity of the landscape. Measures such as levee setbacks (relocation landward) and removal of dyked areas can widen the active floodplain, lower flood height and reduce the risk of levee failure. At the same time, improved design and flexible management restore the connectivity of rivers with wetlands. 'Room for River' programs that aim to reduce reliance on levees typically involve spatial planning, catchment scale management, property relocation and changes in land use. To minimise opposition to change, 'win-win' solutions have been pursued, such as provision of prime residential development opportunities, clay and gravel extraction, coupled with habitat restoration when lowering floodplains, flood-compatible agriculture, tourism and recreation initiatives. These have resulted in multiple benefits for local economies and the environment as well as social and cultural gains (Dutch Government, nd; De Boer and Bressers 2011*a*; Nijssen 2012).

Levees continue to be an important measure in the USA but their problems are well- recognised and ecosystem approaches have become increasingly popular (ASFPM 2008; Freitag *et al.* 2009; Opperman *et al.* 2009; Liao 2014). However the trend in Australia is to increase dependency on levees and while the principles of levee setback in design are understood, ideal alignment can be thwarted for political reasons (Moorhouse *et al.* 2014). A rare proposal to realign levees at a bottleneck reminiscent of overseas 'room for river' strategies, failed to go ahead in the Lower Goulburn Floodplain (Victoria). It was expected to have multiple benefits for water quality, recreation, reduced levee repair, greater levee reliability and riparian health (Water Technology Pty Ltd 2005). The proposal was ultimately abandoned due to opposition from farmers who would have been subject to land acquisition, and a subsequent Federal Government decision not to co-fund the project. The Clarence Floodplain Project (NSW) achieved greater success provides an Australian example of a flexible system that keeps floodgates open most of the time to reverse levee impacts and improve wetland connectivity. Success can be attributed to the project's partnership approach that identified mutually beneficial outcomes for the stakeholders involved, including improved agricultural productivity for landholders (Wilson *et al.* 2010; Clarence Valley Council 2013*a*).

4.2 Factors influencing transferability of adaptive approaches

4.2.1 Problem Recognition

The willingness to adopt a new approach is strongly dependent on a country's ability to recognise problems. More severe floods are anticipated for each case study country, and all have recently experienced high damage bills. However, the scale of potential damages is greatest for the Netherlands, with 65% of its national wealth at risk (Deltacommissie 2008). Similarly, China's flood-prone Yangtze River Basin is also its most economically developed, accounting for around 40% of GDP (Yang *et al.* 2009). In problem recognition, size matters and effective management of flood threat becomes a clear policy priority.

The 'problem' countries seek to address is also subtly different. All are concerned about reducing flood damages. However, in countries with a long history of levee use, the issues with this approach are immediate and visible. Problem recognition is hindered where extensive levee problems have not yet arisen and where options to address flooding are assessed on the basis of expected performance over narrow timeframes (see 'program delivery'). Of the four countries, Australia has invested least in levees. While levee issues are raised in Australian flood reviews, from a political standpoint there is little evidence that Australian governments recognise the problems associated with this option. Investment in new levee construction has increased and state funding mechanisms currently offer little support for alternative options such as house raising or land swap, even when these options are favoured locally (Walsh 2012; Bundaberg Regional Council 2013; Egan 2013; Wenger 2014).

Problem recognition may also be distorted by geographic scales. Where flood management is a local administrative responsibility, issues across broader geographic and temporal scales are less apparent. Levee construction that increases flood height for nearby properties by a mere 10cm is easily dismissed (Aurecon 2013). The cumulative effect of such encroachments over time and across catchments is unlikely to be a priority of locally-sponsored studies.

Problem recognition also relies on stakeholder understanding of hydrological and environmental processes. Following the 2010-11 Australian floods, local communities responded by clearing waterways in upper catchments and removing riparian vegetation, while insurers and local governments called for levees to be built. These measures are likely to increase future susceptibility to flooding across catchments (Parliament of Victoria 2012; see also interviews in Wenger *et al.* 2013). While resilience programs often address community awareness of *where* it will flood and *how to prepare*, there is little activity to raise awareness of hydrological and ecological processes and the consequences of different options. Yet if resilience policies place greater responsibility on local communities, there needs to be a knowledge base for local decision makers to select and for local communities to provide political support for measures that will not be detrimental in the longer term. Simulation software and interactive computer games have the potential to increase community understanding and have been used in the United Kingdom (Sear 2014).

4.2.2 Affordability

The failure of levees in the 2005 New Orleans disaster highlights the consequence of inadequate levee protection and the need for levees to be robust where they are relied upon to protect high value assets. In the Netherlands, the protection standard for riparian land is the 1:1,250 ARI event under the rationale that in the long run, adequate protection is cheaper than the cost of recovery from rare but extreme flood events (Galloway *et al.* 2007; Deltacommissie 2008). However, Australia and the USA, which enjoy a similarly high per capita GDP, have a much lower standard of levee protection. In the USA, levees only need to be built to the 1:100 year standard to be certified and accredited as providing communities with adequate protection for the purposes of the National Flood Insurance Program[43]. Many levees that protect Australian townships don't reach even this level of protection (e.g. a recently proposed levee to protect Gympie's CBD would only afford protection up to 1:30 ARI).

Lower standards for levee protection could be attributed to many factors, but USA and Australian sources suggest that a primary reason is the capital cost for local communities (NCLS 2009; Jabour 2012). Affordability of levees strongly correlates to the value of assets protected, and in rural areas, levee costs can easily exceed avoided damages (Parliament of Victoria 2012: 59). Thus capital cost effectively discourages levee construction. However, perceived financial benefits of levees simultaneously create a high local incentive to build them. Unlike other measures, costs are largely externalised (BTRE 2002). Despite 30% being the standard requirement for local contributions in both the USA and Australia, a recently approved Australian levee included local financing of just 8% (Maranoa Regional Council 2013). Levees increase land values (see Wagga case study, Wenger *et al*. 2013), reduce the costs of flood insurance (Suncorp 2012), and facilitate additional development of flood-prone land through re-zoning (AECOM 2011). Levees also have high visibility, which makes them appealing to both communities and politicians (Smith 1998). Factors influencing the political acceptability of levees are shown in Figure 5.1.

To increase adoption of adaptive practices, perverse incentives that encourage levee building need to be addressed. For example, conditional funding of levees could restrict further development. USA reviews demonstrate that alternative property-based measures such as house raising mitigate flood risk better than levees. Such measures address insurer concerns about repetitive flooding and can potentially lead to incentives through premium discounting.

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[43] When a levee is accredited by the Federal Emergency Management Agency (FEMA), the leveed area is effectively excised from the mapped 1:100 year floodplain. For communities participating in the NFIP, this *exempts* properties in the 'protected' area from mandatory flood insurance, lender notification and floodplain management regulation requirements such as construction standards.

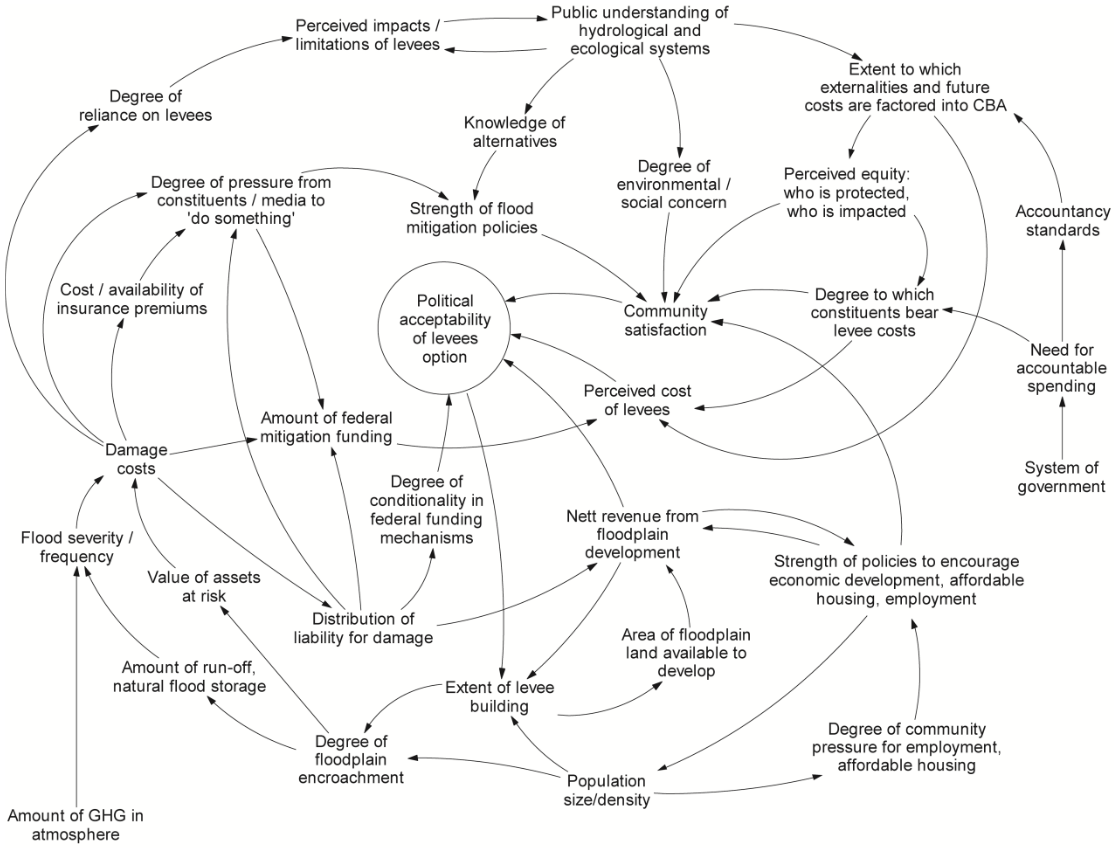
Cost-benefit analyses generally find property-based measures more costly than structural mitigation. However, they have the advantage of incremental payment, better cost sharing with beneficiaries and greater equity in that they are available to all flood prone properties and not just those behind the levee. By accommodating inundation, such measures maintain flood storage and awareness of risk.

Other alternatives, including ecosystem based measures, can be highly cost effective. Ecosystem based measures are self-regulating, have low maintenance requirements and multiple co-benefits (Jones *et al.* 2012; Lal *et al.* 2012). Hallegatte (2009) does not include ecosystem approaches among his examples of adaptation options, but according to his ranking system, they are flexible, reversible, tend to be low cost or 'no regrets', have synergies and are thus highly adaptive. Ecosystem approaches are not without drawbacks. They often require catchment-scale implementation. This introduces a level of complexity that is a significant barrier where flood management is a local government responsibility. This needs to be addressed in program delivery. Ecosystem based approaches also rely on land being available for implementation, and just as levees will overtop when floods exceed their design height, natural defences will be insufficient to deal with events above a certain magnitude (IJC 2000; Kousky *et al.* 2011). However, unlike levees, natural defences will not fail completely but delay and reduce flood magnitude regardless. Nor is the choice 'either or' as ecosystem based measures can be incorporated into the management of existing levee systems.

4.2.3 Program Delivery: decision-makers, timeframes and spatial scales

Case studies highlight a significant difference in program delivery between countries. While the Netherlands and China are unitary governments and centralise decision-making, the USA and Australia are federations where state governments have constitutional responsibility for natural resource management, and by extension, for flood management. State governments commonly devolve much of this responsibility to local governments. However, the USA's Federal Government has invested more than Australia and has a much more direct role in in flood management (through disaster relief, the NFIP and other programs administered by the Federal Emergency Management Agency and the United States Army Corps of Engineers) and it is prepared to use its financial leverage to impose conditions on recipient communities (Wright 2000; Niebling *et al.* 2014).

Figure 5.1: Factors influencing the flood management options favoured by Australian state governments. *The political acceptability of levees is subject to complex inter-relations between many factors. Their relative importance is not fixed and often depends on circumstances specific to an event (for example, the type of media coverage, the values and policies of the government of the day). This complexity illustrates that to increase the probability of adaptive approaches being adopted, interventions (e.g., increased public understanding) cannot be applied in isolation and a wide array of other influences needs to be considered.*



Australia's Federal Government has the least influence over flood management of the countries studied, partly because governance style tends to favour non-interventionist approaches, and partly because lower national investment results in lower leverage (massive recovery bills following the 2010-11 floods might change the federal stake). The 'resilience' approach is tailor-made for a non-interventionist national government, as it is non-specific and any measure states wish to implement can be marketed as 'improving resilience', regardless of how adaptive or resilient it is in the long term (Walsh 2011; Queensland Government 2013*d*). Specific measures endorsed nationally in Australia include greater access to flood information, risk assessment and development planning, and there is no authority or financial inducement to enforce the latter. The Federal Government agrees to contribute funding to measures on the basis of locally-commissioned flood studies and risk assessments. However, local community interests (and state interests) do not necessarily equate to catchment or national interests. While federal governments are expected to pay for damages, flood management in both Australia and the

USA is a state government concern. This creates incentive barriers as practices that increase flooding (such as development of floodplains) also increase state income and future demand for levees (Abel *et al.* 2011). Where levee building is subsidised by national governments, there is also less incentive for states to implement responsible development planning. This is particularly evident in the USA case study where the national flood insurance program has created perverse incentives that have encouraged levee building and development of floodplains. When levees are built, development within accredited levee-protected areas is exempt from NFIP requirements, making it attractive to build levees and increasing potential consequences (Burby 2006; ILPRC 2006; ASFPM 2007; NCLS 2009).

It has already been noted that geographic focus is important for problem recognition. It is also important for program delivery. The experience and observations of all four countries demonstrate the importance for floods to be managed using natural catchment boundaries. New development, levees, vegetation and wetland management all impact the velocity and depth of water flowing downstream and different measures are needed in upper, middle and lower catchments. Unitary governments have greater ability to coordinate flood management across catchments. In the Netherlands, integrated catchment management is reinforced through international mechanisms, notably the European Water Framework Directive. Where program delivery is confined to local administrative boundaries, as is often the case in federated systems, the result is a patchwork of un-coordinated measures.

Figure 5.2 illustrates the delivery of flood mitigation programs in Australia, while Figure 5.3 illustrates similar processes in the Netherlands. In Figure 5.2, approved processes and methodologies are needed for democratically-elected governments to demonstrate effective and responsible public spending. Delivery of national and state programs relies upon risk assessment and local flood studies are key to this process. Local flood studies provide information on susceptibility to flooding and enable options assessment. However, research findings suggest that this type of program delivery favours levees.

Methodologies require cost-benefit analysis (CBA), and use discount rating. Australia’s Rapid Appraisal Method uses a discount rate where “little weighting is given to events beyond about 30 years” (State Government of Victoria, 2000), which is inadequate for assessing structures that have on-going liabilities and contribute to cumulative impacts for centuries. Discount rating thereby institutionalises short-term timeframes. Tobin (1995) criticises CBA on the basis that apparently high levee benefits from avoided damages are misleading, if not fallacious (Tobin, 1995). This is due to the frequent observation that levees stimulate development of floodable land that might not otherwise have occurred, magnifying damages in the event of levee failure (Tobin 1995; Burby 2006; ASFPM 2007). Another issue is that CBA has great difficulty accounting for indirect and intangible impacts of proposed measures and weighting of these is discretionary. Short-term economic considerations tend to be prioritised over environmental health and indirect impacts to other sectors or community values such as providing amenity and protecting water quality. A similar situation is found in the USA where application of the Water Resources Council *Principles and Guidelines* require that federal projects use CBA to demonstrate contribution to national economic development (ILPRC 2006; ASFPM and NAFSMA 2007; Freitag *et al.* 2009). The fact that CBA regularly finds levees the most desirable option suggests that decision-making tools themselves need to be assessed for their adequacy in delivering adaptive outcomes.

Cost benefit analysis was considered too narrow for Dutch decision-makers when they determined their new approach to flood management: "good political choices depend on both visions and calculations" (Deltacommissie 2008). A unitary government can perhaps afford to have visions whereas a federal government has to justify any involvement in state affairs, and dispassionate calculations provide 'evidence' for federal and state governments to support locally-endorsed measures.

Private sector interests such as engineering firms also play a role in the decision-making process which may influence the type of flood mitigation options selected. Flood studies require technical expertise and engineering firms are able to provide this service. While construction is subject to tender, the same firm that carried out mitigation options studies favouring levees may later be awarded contracts to implement or supervise subsequent phases of work. Examples include Gympie (Aurecon 2013; Gympie Regional Council 2013), and Roma (Maranoa Regional Council, nd). There is no suggestion of malpractice in these examples – indeed flood studies are often peer reviewed. However, the possibility of being awarded subsequent contracts does highlight a potential conflict of interest for firms responsible for assessing and recommending mitigation options. Moreover, industry bias means that engineering firms are most likely to favour engineering solutions. Thus, an unintended consequence of the push for flood information and risk assessment could be greater investment in structural works. This tendency is reinforced by state government grant programs which on the one hand require that flood studies cover a wide range of options (including voluntary purchase), and in the same guidelines deem land purchase ineligible for state grants (Queensland Government 2013*a*). This could form an example of 'hydraulic bureaucracy' in Australia (Molle *et al*. 2009).

Timeframes are an issue not only for CBA, but also budget cycles. Many Australian government grants require projects to be completed within a twelve-month period (Queensland Government 2013*a*). This favours once-off construction projects. It is little suited to the implementation of ongoing measures such as house-raising or voluntary purchase which can span decades (De Boer and Bressers 2011*a*; Wenger 2014). This style of program delivery has limited flexibility when presented with windows of opportunity such as the wake of a flood disaster (the 'reorganisation' phase of the adaptive cycle, Walker and Salt 2006) and *ad hoc* funding initiatives following recent disasters have primarily responded to political pressures to fund structural measures. Program limitations can be surmounted by forward planning and funding arrangements. The Netherlands has an exceptionally long planning horizon, beyond 100 years, to implement its Delta Programme and has established a separate fund and a Delta Act to insulate its long-term strategy from political vicissitudes. Flexibility and opportunism are features of project implementation (Deltacommissie 2008; De Boer and Bressers 2011*a*; Nijssen 2012).

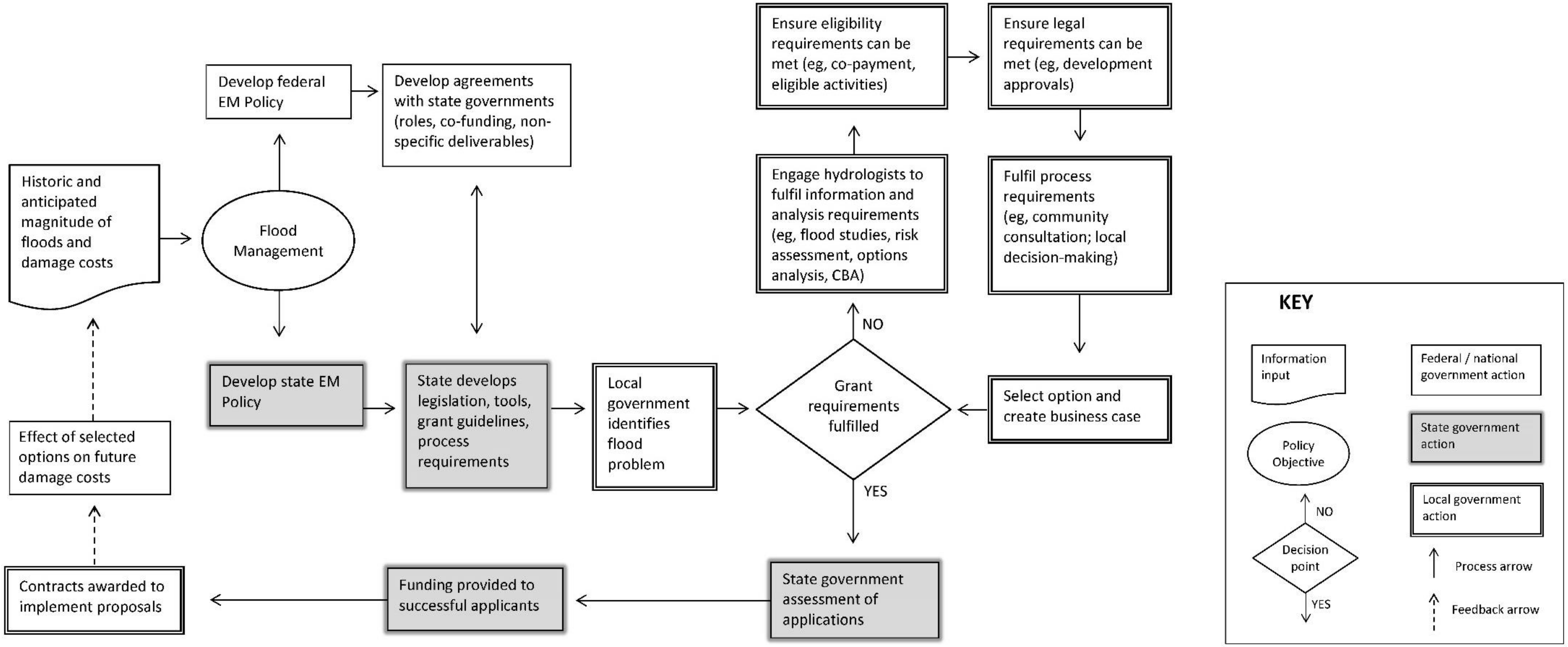


Figure 5.2: Delivery of flood management programs in Australia *(e.g., the National Partnership for Disaster Resilience and Queensland State Government's Natural Disaster Resilience Program and Royalties for Regions). Grants are competitive and, especially for large infrastructure projects, are often awarded in more than one stage. The outcomes of an initial grant (e.g. a flood study and risk assessment) may be used to justify progression to a subsequent stage such as the design or implementation of selected measures. State governments have a key policy role and determine eligible grants activities, which may be restricted to infrastructure. While states can directly commission flood projects, this is less common. Problem identification, flood studies, options analysis and selection are usually undertaken on a local (often township) scale by municipal councils, or occasionally by catchment management authorities (for example, in Victoria). Decisions are strongly influenced by hydro-engineering firms. Note there is an unequal distribution of damage costs, whereby national government is liable for the majority of public reconstruction, while having the least power to implement effective mitigation. No government level is responsible for private losses that arise from development zoning decisions. The feedback loop is thus imperfect.*

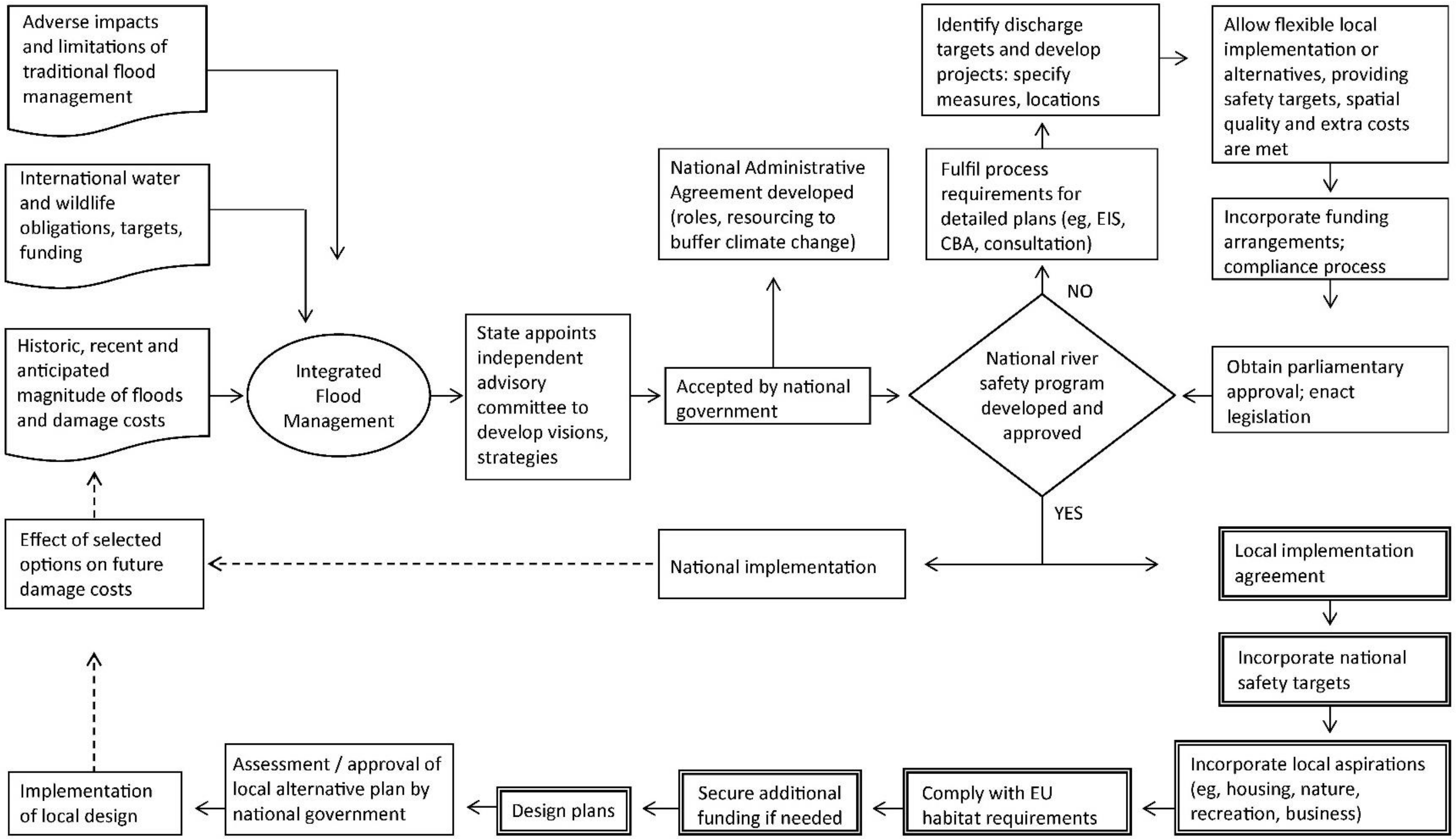


Figure 5.3: Delivery of flood management programs in the Netherlands *(as typified by the Room for the River Program). Flood safety is a national government responsibility and recent keystone policy documents have been developed by independent committees. Flood management may also be initiated at the catchment level (e.g., the Regge Vision 1998 led by the Waterboard of Regge and Dinkel). Regional projects may be subsidised by national and provincial governments where they contribute to national, provincial or EU goals and targets, such as the EU Water Framework Directive or the National Ecological Main Structure (creating wildlife corridors that may also be compatible with flooding). EU and National influence, and funding, have encouraged multifunctional land use and integrated water resource management. National government is responsible for damages within dyked areas.*

There are also differences in the expertise pool drawn on by Dutch and Australian policy makers. In Australia, national flood policy is informed by expert bodies, such as the National Flood Risk Advisory Group (Wenger 2013). This group, meeting twice per year, is composed of government officials from different agencies and levels of government and also includes insurance industry and community safety research representation. The composition reflects the national government's coordination and resourcing role. The insurance industry, which advocates for flood levees to reduce repetitive flood damage, is an influential player. Following recent floods, a National Insurance Affordability Council was formed to advise government on mitigation projects (Gillard 2013*b*).

By contrast, current Netherlands flood policies, including the 2000 water policy 'A Different Approach to Water' and the Delta Programme largely drew on the findings of limited-term independent committees. Deltacommissie members included engineers, an economist, hydrological, soil and climate scientists, and experts in sustainable development, agriculture and spatial planning. The Committee's mandate encouraged creative solutions and the range of expertise encouraged a long-term outlook integrated across sectors.

Transferability of adaptive approaches to new countries depends to a large extent on the adaptive capacity of their institutions. In the context of sustainability, adaptive institutions need to be persistent, purposeful, have access to a broad array of high quality information, be inclusive and flexible (Dovers 2005). The Netherlands model for program delivery displays many features of adaptive governance. Deltacommissie membership included a high level of expertise across diverse fields. Recommendations accorded with broad societal values and achieved widespread support. Subsequent implementation of the Delta Fund and Act ensured persistence and purposeful mandates that were also flexible enough to accommodate future uncertainty. The Netherlands bases its policy on the projected (worst scenario) quantity of flood waters it will need to accommodate in national river systems and floodplains and specific measures able to increase flood storage capacity. Program delivery is therefore applied to broad spatial scales. However, it also encourages flexible, local implementation.

Australian institutions appear less adaptive. Australia's national resilience strategy does little to identify approaches to flood management that are truly adaptive. Indeed, program delivery and institutional incentives appear to encourage structural options. Some players have disproportionate influence while others are not represented at all. Decision-making is short-term and based on highly localised information. The primary consideration is the cost-effectiveness of individual local options rather than win-win outcomes across catchment sectors and long term sustainability. Using Dovers' (2005) criteria, this suggests a lack of adaptive capacity that is likely to prove a strong barrier to the transferability of adaptive approaches. This finding is relevant to other federated states and countries with similar devolved program delivery arrangements. It suggests that recent global trends to decentralise disaster management, noted by Lal *et al.* (2012), will not always achieve the best adaptation outcomes.

5. Conclusions

Management measures such as levees have long been used to protect against floods and they are an appealing solution. External funding, incentives of cheaper flood insurance and the illusion of security instil confidence in communities and enable the on-going development of settlements in hazardous areas. However, considering the widespread degradation of riparian ecosystems, it is questionable whether the use of levees is truly adaptive in the long term. Their proliferation adds to the vulnerability of water resources and human communities, and reduces the natural ability of landscapes to buffer extreme weather patterns of flood and drought. While levees can reduce localised flooding in the short term, their effects on hydrological and biological systems, and their role in facilitating inappropriate land use and development of risky areas render them a maladaptive solution.

Levees play a prominent role in the flood protection of countries such as China, the Netherlands and the USA, and the unintended consequences of using them are clearly visible. Where levees are integral to flood management, much can be learned from these countries about improving their design, operation and administration. Australia's experience is less extensive but already management issues similar to those experienced in the USA are starting to occur. Levees are no 'quick fix'. They require ongoing administrative, financial and regulatory commitment.

Increasing flood frequency can create pressure to build levees. However, levees are likely to become increasingly unreliable as a consequence of climate change. Some countries are seeking to reduce dependency on levees and are developing innovative ways of addressing flood risk. The challenge is to transfer such approaches to other countries.

Comparative analysis suggests a number of factors influence transferability. These include problem recognition, financial incentives, decision-making processes and program delivery. Federated systems face particular challenges providing the necessary leadership and unified catchment approach necessary for effective flood management. Responsibility is often devolved to local governments which lack both the resources to fund flood mitigation, and the administrative authority to manage floods on a catchment level. This research suggests that if governments wish to adapt to future flood threats that a) they need to be clear about what constitutes an adaptive approach and articulate this in flood or disaster resilience policies, and b) if adaptive options are not being implemented, they need to closely examine their program delivery mechanisms and decision-making methodologies to identify sources of bias. This means rules and methodologies surrounding the selection of on-the-ground measures may need to be assessed; following the Dutch model, the identification of approaches that would best serve the national interest should not be restricted to cost-benefit considerations but need to encompass broad societal goals and values that are inclusive of other sectors.

Acknowledgements

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Publication 6 preamble

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Publication 5 indicated that Australia's use of levees was out of step with trends in other countries. While most case study countries recognised the limitations of levee use and the need to reduce reliance on structural approaches, Australia seemed to be increasing its investment in levee building. As to the question of whether Australia could take a short cut and learn from these countries, thereby avoiding future levee problems, this also seemed somewhat doubtful. First-hand experience of levee problems seemed an important element for motivating change. Further, **publications 3** and **4** indicated that Australia's institutional context was not ideal for implementing ecosystem based approaches, while **publication 5** suggested that existing arrangements appear to favour the use of structural approaches.

This was somewhat disappointing. However, given the recent surge of interest in levees in Australia, an in-depth review of levee performance seemed timely. There were significant management, cost and performance -related levee problems overseas. How evident were these problems in Australia? Australian flood inquiries had raised issues relating to levee use and management. This was particularly the case for Queensland where the QFCI had noted a complete absence of levee regulation at state level and of the handful of local councils with local levee laws only one planned to retain them (QFCI 2012). However, the floods and flood inquiry findings had prompted changes to levee arrangements and these needed to be investigated.

Many sources, including Victoria's ENRC inquiry and interviewees made a clear distinction between levees that protect towns; rural levees; and levee-like structures (ostensibly built for other purposes but intentionally or inadvertently also diverting floodwater). These sources proposed that town levees were more justifiable than rural levees. A review of levee performance in Australia would therefore need to cover different types of levee.

The aim of **publication 6** was to review levee performance, legislation, policy and guidelines in Australia. This included reviewing development controls, given that 'planned' development will one day transform into 'existing' development in need of protection. This builds on **publications 1** and **3** findings, which indicated Australian development controls were inadequate.

Provisions surrounding cumulative impacts and catchment management were of particular interest. This was for two reasons. Firstly, lack of consideration of catchment-wide and cumulative impacts over space and time are a key reason for negative levee impacts. Another reason was a seed of doubt sown during a conference when an audience member challenged me, suggesting that flood management was already catchment based. Although I was able to respond (based on my research) that there were different provisions in different states and that some, such as Victoria, had much better catchment based provisions than others, the challenge concerned me and I resolved to study provisions for catchment-based flood management and cumulative impacts in detail, not only for the two states I'd hitherto focused on (Victoria and Queensland, as they had produced detailed post-disaster inquiry reports) but also for New South Wales.

To this end, as background research for **Publication 6**, I embarked on a comprehensive legislation and policy review, covering over two hundred documents relating to levees, levee-like structures, development planning and catchment/floodplain management (listed at Appendix 1 of **Publication 6**). Detailed notes were taken of each document and this was published online as supplementary information for **Publication 6**. The journal did not have the facility for online supplementary information so it was agreed for it to be published on the Bushfire and Natural Hazards Cooperative Research Centre website. The link was included in the article. As the document is long, it was decided not to include it as an appendix to the thesis. However, it can be accessed at: http://www.bnhcrc.com.au/research/economics-policy-and-decision-making/1067 (click on the 'resources' tab).

Building walls around flood problems: the place of levees in Australian flood management

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Abstract

Recent Australian floods have resulted in many changes to levee provisions in Queensland, Victoria and New South Wales. It is therefore timely to review levee issues and current state arrangements. This paper investigates the use of levees as an adaptation measure to address climate change. It also looks at the performance and reliability of Australian levees; environmental impacts; and the relationship between levees and the development of flood prone land. Despite recent changes, there continues to be much scope for improving floodplain development planning and the assessment and management of levees. Development controls continue to be inadequate and this will fuel future demand for levee protection, while lack of development controls behind levees is likely to lead to greater consequences when levees fail, a scenario more likely due to loss of climate stationarity. While levees provide incremental adaptation, they do not offer a long term solution. However, transformational adaptation measures used in many places overseas are poorly supported by Australian funding programs. Long term adjustments need to be planned and funded and appropriate incentives and decision-making structures need to be put in place.

Keywords: adaptation; climate change; floodplain management; flood mitigation; flood policy; levees

1. Introduction

In 2010-2013, eastern Australia experienced widespread, major flooding and unprecedented damage bills. This led the IPCC to conclude that 'Australia has a significant adaptation deficit in some regions to current flood risk' (IPCC 2014). Following the floods there have been numerous inquiries at all levels of government and a significant re-assessment of legislation, policy and programs relating to disaster management. The push for reform is driven not only by the high cost of recent damages but the expectation that future damages will rise still further due to climate change and population pressure (DAE 2013; Productivity Commission 2014*a*).

The Productivity Commission's draft report on disaster funding highlights an imbalance between disaster prevention and post-disaster funding (Productivity Commission 2014*a*). The Commission proposes that funding for prevention be significantly increased from its current ~A$30 million per year to $200 million per year. It also recommends removing prescriptive funding conditions, to give states and local government greater spending autonomy. This would apply to both mitigation and recovery funds, which could dramatically increase the funds available for prevention. This raises the crucial question of how that money would be spent.

Adaptation theorists argue that large scale engineering solutions to floods tend to have highly localised, short-term benefits that are often maladaptive across broader scales and sectors (Adger *et al.* 2005; Cardona *et al.* 2012; Barnett and O'Neill 2013). Engineering responses such as levees are often characterised as 'incremental' adaptation and while this may be appropriate in some cases, there are often trade-offs that compromise long-term transformational change (Lavell *et al.* 2012; O'Brien *et al.* 2012).

Incremental adaptation is often favoured by policy makers as it allows the *status quo* to continue. For example, in response to repeated flooding, the use of structural mitigation may allow people, industries and economies to remain in place unchanged and to intensify. Should the mitigation measure prove inadequate, for example, due to an underestimate or change in risk (or risk tolerance), it may be augmented incrementally. However, as in the Netherlands, such solutions may eventually encounter physical or economic limits, prompting the reassessment of traditional approaches (Deltacommissie 2008).

Transformational adaptation commonly addresses underlying root causes (such as vulnerability and institutions) rather than symptoms such as flood damage. A change in mindset is often needed to effect transformational approaches. For example, the following articulates changing attitudes towards flood management in China:

> The direct losses caused by the 1998 Yangtze flood … should force us to reconsider the human-river relationship. We should change the strategy from 'keeping the flood away' to 'giving the flood way'
>
> (Yin and Li 2001: 108)

In this example, 'giving the flood way' may mean relocating people out of natural flood detention areas, restoring ecological function and providing people with new and profitable flood-compatible livelihoods and long term safety (Pittock and Xu 2011; Wenger 2015*b*). These measures and activities are the on-the-ground manifestation of transformational adaptation.

In the past, the use of structural solutions to flooding such as levees has been limited in Australia by lack of funding from the Federal Government (Smith 1998). Greater funding from the Federal Government, and absence of policy direction regarding their use, could result in a 'preponderance of structural measures' and reduction in the use of non-structural measures, as observed by Cutter *et al.* (2012). Ultimately this could reinforce community expectations that badly sited development will be offered increasingly costly protection and delay transformational change, such as accommodation or relocation (Reisinger *et al.* 2014).

Repeat flood damage in the years following the 2010-11 events and the prospect of worsening flood risk in the future have prompted strong pressure by many stakeholders, including the insurance industry and state and local governments, for investment in structural mitigation such as flood levees (Milliard 2012; Suncorp 2012; Crisafulli 2013; Walsh 2014). It is therefore pertinent to ask whether this is the best solution for Australia's flood problems or whether policymakers should be focusing on other options. It is the aim of this paper to provide a review of Australian levee use and management to help answer this question. It does this by assessing three aspects of levee use and management:

- the performance and reliability of Australian levees;
- the suitability of levees as an adaptation measure for changing risks; and
- regulatory and administrative arrangements for levees in Queensland, New South Wales and Victoria.

2. Methods

This review investigates the use and management of levees to mitigate catchment flooding in Queensland, New South Wales and Victoria. Historically, these states experience the highest flood damages and two have recently held state-wide flood inquiries with recommendations relating to levees (BITRE 2008; Parliament of Victoria 2012; QFCI 2012) while the third is also implementing changes to levee management (NSW Government 2013*a*). This offers the opportunity to assess current issues and recent changes to state arrangements. Specific issues explored include incentives for levee construction; environmental performance; impacts on people elsewhere; safety; and the suitability of levees as an adaptation measure for future threats such as climate change.

Literature review was the primary research method, drawing on a broad range of sources such as academic journals, government reports and the Floodplain Management Association furnished examples of past and emerging levee issues. Flood studies and flood management studies and plans supplemented these examples with more detailed information about flooding in individual towns and the way in which regulations are applied and decisions are made. Media releases, policy documents and government funding program guidelines offered insight into policy preferences. Reference was also made to international experience and to interviews with flood experts conducted following the 2010-11 floods (Wenger *et al.* 2013).

A separate review was also undertaken to determine levee-related requirements in each state. For the purposes of this study, a levee was taken to include levee-like structures, such as irrigation infrastructure and transport networks.

As levee-like structures are not always included in the legal definition of a levee, this sometimes necessitated a broader search of regulatory documentation. Research also covered flood-related development controls, given that inadequate controls may fuel future demand for levees. Over two hundred documents were checked including legislation, subordinate regulations, guidelines, policy and funding programs. Documents surveyed are listed in Appendix A and findings are presented in section 3.9.

3. Discussion

3.1 The history of levee building in Australia and recent trends

Levees have been used in Australia for over a hundred years, with some of the earliest levees built in the 1890s (Maddocks *et al.;* 2007DSE 2012*a*). However, for much of its history, Australian levee building has been *ad hoc* and has received little support from state or federal governments. It was not until the 1970s that the Federal Government started providing grants and levee building became integrated into comprehensive floodplain management (Smith 1998).

Urban levees vary in extent and complexity. The Hunter Valley Flood Mitigation Scheme, built to protect the city of Maitland (NSW) following the 1949 and 1955 floods, offers 1 in 20 AEP[44]

[44] Annual exceedance probability (AEP) is the probability of exceedance of a given discharge within a period of one year (Engineers Australia, 2015). For example, a discharge that has a probability of being exceeded once every 20 years (1 in 20 AEP) has a 5% probability of being exceeded in any given year (5% AEP).

protection and consists of 170 kilometres of levees and flood control structures (Evans *et al.* 2007). In Victoria, the longest urban levee is a 20.3 kilometre ring levee encircling the town of Kerang, designed for a 1 in 100 AEP event (DELWP, pers.comm; Gannawarra Shire Council 2011). Upgrades and additional levees were approved following the 2011 flood (which exceeded 1 in 100 AEP). In Queensland, Goondiwindi's levee banks were originally built following three major floods in 1956. They have been augmented in height and length several times. They are currently a little over 20 kilometres in length and are designed for a 1 in 100 AEP event (Goondiwindi Regional Council 2011).

Levee building in Australia is reactive and reflects weather patterns. Periods of successive floods are often interspersed with extended droughts due to natural climate cycles (Kiem and Franks 2004; Verdon *et al.* 2004; Pui *et al.* 2011), and calls for new or upgraded levees follow each spate of floods. The recent floods of 2010-2013 are no exception, and there has been a surge in levee proposals and grants funding (Appendix 3, Walsh 2012; Gillard 2013*b*; Queensland Government 2013*c*). The result is a gradual, cumulative increase in the number of the nation's levees.

The total extent of levees in Australia is hard to gauge as information is not collected, or is unavailable (Table 6.1). The Victorian government has maintained information on levees since 1998 through its flood transfer data project, including topographic plans of levees, irrigation channels and bridges. Information is now held in the Victorian Flood Database with updates on levee ownership, height (in metres, AHD[45]), condition and modifications. Both levees and 'flood structures' (where 'levee' is not the primary function) are included in the dataset (Gauntlett and Cawood 2000; State Government of Victoria 2009). The database is also a repository for flood extent overlays or historic flood levels collated from other sources. Being a GIS database it is versatile and information can be incorporated into flood modelling projects to assess flood behaviour. This is used to inform emergency response and land use planning. The database is updated as information becomes available, for example, when there is a levee audit. Levee audits occur intermittently and are usually triggered by major flooding or investigation of flood mitigation options, so there may be inconsistencies and data gaps. Recent audits were conducted for urban levees (outside Melbourne) and rural levees across northern Victoria in 2011-12 (DELWP, pers. comm.).

NSW is currently seeking to collect levee information about urban levees through its levee audit review. It is expected to feed into the new NSW flood database project, an ongoing maintenance management tool that will also alert emergency response agencies to reliability

[45] Australian Height Datum, or height in relation to average sea level (1966-1968) used in Australian mapping and surveying.

issues (NSW Government 2013*a*). Information being collected includes purpose, ownership, age, design, location, length, design flood, geotechnical information, maintenance history and environmental restrictions. NSW also has a controlled works database, covering both rural levees and irrigation-related development such as off-river storage, above-ground channels and drains. The database records ownership, approval and inspection dates and development conditions. However, much information (such as maps and designs) is held on individual controlled work files, making it unsuitable for modelling flood behaviour and difficult to extract overall figures. Queensland's levee arrangements are rapidly evolving but it currently holds no centralised data.

Table 6.1: Information on the extent of levees in three Australian states.

State	Urban levees[1]	Number of towns with levees	Rural levees	Levee-like structures	Information source
Queensland[2]	44 levees.	Number of towns not provided.	4 councils reported > 100 levees. 1 council reported 1,000 levees. Others did not know.	Not known.	(Queensland Government 2013*c*)
NSW	Urban levee review currently underway.	Urban levee review currently underway.	Controlled works database and controlled works files hold information on rural levees and earthworks. Extent is not readily available due to database configuration. The database is not publically available.[3]		(NSW Government 2013*a*)
Victoria	91km	32	3,920km	Incorporated into database maps, models	(DELWP, pers. comm.)

1 *Urban (or town) levees* are usually publically-owned and reduce flood frequency for assets, such as residential housing or commercial centres within town or city boundaries. *Rural levees* are more often privately owned. They reduce flooding for land uses such as flood-sensitive crops or dairy and may extend for hundreds of kilometres. They usually afford lower protection than urban levees. Rural dwellings and farm buildings may also be protected. The primary purpose of *levee-like structures* is not flood protection but intentionally or unintentionally they behave like levees by forming a barrier to natural flows. For example, irrigation embankments and raised transport infrastructure.
2 Based on a state government survey of Queensland's 73 councils, of which 40 responded.
3 Information provided by the NSW Office of Water, 2015

Information is a prerequisite for effective levee management. Depending on the type of information collected, it can be used for maintenance management, emergency response planning, monitoring compliance and assessing the cumulative impacts on flood behaviour or the environment. The patchy nature of levee data in most states, indicated in Table 6.1, is likely to be a result of flood management being primarily assigned to local governments. Local data collection is also problematic in many places. However, recent trends in all three states are towards stronger levels of levee regulation and administration at both state and local government levels (NSW Government 2013*a*; Queensland Government 2013*c*; State of Victoria 2013*b*).

3.2 The appeal of levees

Levees are often justified on the basis that they reduce flood frequency, and thereby damage costs. However, flood frequency is only one side of the risk equation and levees also increase potential flood consequences. In the USA, levees have been criticised for encouraging additional development. Those who live in leveed areas (where the levee is certified as protecting against the 1 in 100 AEP design flood) are not required to pay flood insurance under the National Flood Insurance Program. Nor do they need to comply with flood resilient construction standards. This encourages levee building and floodplain development (ASFPM 2007; Galloway *et al.* 2007; NCLS 2009). A study of 1,200 American communities found a positive correlation between the degree to which structural mitigation is used and the amount of development that takes place following completion, greatly increasing future damage potential. This was a major factor contributing to the magnitude of the New Orleans disaster in 2005 (Burby 2006).

While Australia does not have a national insurance program, incentives are similar. Australian flood insurance providers offer substantially cheaper insurance to properties behind levees than to those without levees (Suncorp 2012). Australian levees also enable the development of land that had previously been considered too risky to build on. This is sometimes promoted as an advantage of levees in Australian flood studies (John Webb Consulting Pty Ltd 2009; AECOM 2011) and supported in regional development plans and local planning schemes (State Government of Victoria 2014*b*; State of Victoria 2014*c*). Even where funding agencies impose conditions on levee building to restrict additional development, this is hard to enforce. Tasmania's new Launceston levees were jointly funded by federal, state and local governments as part of a package of agreed measures that included preventing new development behind the levees. The Council subsequently decided to reverse planning restrictions but was prevented by the threat of withdrawal of state and federal funds (Atkins and Vince 2009). The project has recently been completed and there are already plans to attract development to designated development sites in the newly protected Inveresk precinct (LCC 2013). In a further example, Queensland Government guidance on state interest for natural hazards, including floods, states that intensified land use is acceptable in areas where 'mitigation through built form responses' has mitigated risk to 'an acceptable or tolerable level' (Queensland Government 2014*c*). These examples suggest that while reducing flood frequency, levee funding should also be considered a development subsidy that ultimately increases the amount of assets and people at risk. Some jurisdictions recognise this and the NSW Floodplain Development Manual advises development controls be considered in levee protected areas (NSW Government 2005).

3.3 Levee reliability and performance

US reviews argue that referring to levees as flood risk 'reduction' structures rather than 'protection' would more accurately reflect their reliability (ILPRC 2006), as all levees will fail to prevent a flood that exceeds design height. An often-cited Australian example is the Nyngan flood of 1990, where an estimated 1 in 200 AEP event required most of the town's 2,500 residents to be evacuated by helicopter (Wood and Fishburn 1990; SCARM 2000).

There are many recent examples of urban levees overtopping or coming very close to this, including Kerang and Goondiwindi (2010-11), Charleville (February 2012), Wagga Wagga, the largest inland city of NSW (March 2012), Nathalia (March 2012), Grafton and Maclean (January 2013), and Kempsey (February 2013). Kempsey's levees (some with a design height of less than 1 in 10 AEP) overtopped in 2013 and flooded the CBD (Kempsey Shire Council 2013). However, to date, failure of urban levees has been relatively uncommon in Australia. Formal town levees successfully withstood the 2010-11 floods in both Queensland and Victoria (DSE 2012*a*; QFCI 2012).

Rural levees are less reliable and 114 levees breached during Victoria's 2010-11 floods (Comrie, 2011). In the Lower Goulburn Floodplain, levees line the river banks almost continuously from Shepparton to Echuca, and in a 1 in 10 AEP event they overtop or fail randomly costing an average A$74,000 in annual repairs. Where the levee corridor reaches Yambuna Choke, levees overtop or breach on average every two years (Water Technology Pty Ltd 2005).

The performance of levee-like structures during the 2010-11 floods was not reported by flood reviews or government agencies. Levee-like structures have varying functions and ownership, and unlike levees, they are unlikely to be built to a 'design flood height' (this is not always the case and sometimes raised roads can be built for the dual purpose of transport and flood mitigation). Legislative and policy arrangements may be quite different for different types of structure. While urban levees are publically owned and are usually subject to formal design and maintenance requirements, privately-owned irrigation infrastructure (and many rural levees) are the responsibility of landholders. Providing they have been built to comply with local planning schemes and state laws, the maintenance of privately owned structures is largely unregulated, making them less predictable in a flood.

Levees sometimes make flood damage worse due to the release of high energy water when they breach. They may not protect against all sources of flooding and they can trap water on the wrong side of the levee, preventing drainage. The Ensham mine is a recent example of levees protecting against river flooding but not against surface run-off from rain that fell over the site itself (QFCI 2012). In another instance, Charleville was flooded in March 2010 by Bradley's Gully, a tributary of the Warrego River that runs through the town. Its levees were only designed to protect against flooding from the Warrego River. Water became trapped behind the town's levee bank increasing flooding and part of the levee needed to be demolished to enable water to drain out (Patterson *et al.* 2012). Similarly, the town levee at Robinvale, Victoria had to be breached in January 2011 to drain water from the town (Parliament of Victoria 2012). In a rural example, levees in Victoria impeded drainage of farmland to such an extent that floodwaters sat on the land for a period of three and a half months (Gannawarra Shire Council 2011). Levees do not necessarily prevent all sources of flooding and by prolonging the duration of flooding they can result in worse damage than natural floods and delay recovery.

Levee age and maintenance are significant issues affecting reliability overseas (ILPRC 2006; Galloway *et al.* 2007; NCLS 2009). Ongoing maintenance, repair and upgrade are costly and local communities often find them unaffordable, with deterioration the result. The National Committee on Levee Safety (USA) reports that following decades of neglect, it would cost $30 billion to restore California's levees (NCLS 2009).

Few statistics are available on the average cost of levee maintenance, however they are likely to be highly variable depending on factors such as age, design, climate, the frequency of exposure to floods, labour and material costs. The Netherlands spends an estimated €100,000 per kilometre per year (A$144,000) to maintain its primary flood defences. Annual maintenance costs per kilometre of levee in Vietnam are five times lower (Linham *et al.* 2010). The more levees Australia builds, the greater this ongoing liability will become.

Climate change also has implications for levee maintenance costs. Dry climates reduce protective vegetation cover and cause cracking which can increase maintenance needs and reduce the reliability and longevity of levees (LWRRDC 2002; CIRIA 2013).

Ongoing costs of Australian levees are largely incurred by individual councils. Levees are expected to have a design life of at least forty years (McLuckie *et al.* 2014), and local affordability may emerge as an issue as levees age beyond this. There are already indications that this is the case. In Victoria, councils responsible for levees at Horsham, Wangaratta and Echuca, have disputed their responsibility for levee renewal, replacement and extension, with one council also disputing responsibility for regular levee inspection and maintenance (Parliament of Victoria 2012). Victoria is currently in the process of strengthening its policy on local ownership and maintenance of urban levees and future funding may be contingent on formal management arrangements (State of Victoria 2014*b*).

3.4 Levees and climate change adaptation

Existing levee design standards may be compromised by climate change. In its most recent report, the IPCC anticipates increased frequency and intensity of flood damage to Australian infrastructure and settlements. For most regions in Australia there may be increases in rainfall intensities interspersed with more frequent drought in southern Australia (Reisinger *et al.* 2014). It follows that levee design heights, based on the assumption of stationary time series of flood information, will become increasingly unreliable.

Periodic relicensing is a strategy sometimes applied to dams which could also be used for levees (Pittock and Hartmann 2011). Relicensing could take account of changes in levee condition and flood frequencies that a levee can be expected to accommodate as a result of climate or catchment changes. As proposed for dams, time limited approvals could facilitate adaptation to changes and modifications where levees are shown to have significant adverse impacts. However, in the USA, levee recertification, and the financial implications of decertification are prohibitively expensive (ILPRC 2006) and Australian governments already struggle to fund maintenance and audits of levee systems. A sophisticated relicensing system may be unrealistic.

Most Australian jurisdictions have policy and planning arrangements in place to address flooding related to sea level rise (Gibbs & Hill 2011) but less attention is given to catchment flooding, as precipitation changes are subject to higher levels of uncertainty and it is difficult to translate projected impacts to the local scale. National strategies to address changes to rainfall-related flooding include resilience enhancement, improved risk information and revision of regional flood estimation guidelines (Wong 2008) and most states expect to incorporate climate change into flood management using revised Australian Rainfall and Runoff guidelines (see section 3.9). However, *knowledge* of risks is not sufficient to prevent new development from being approved on flood prone land (Productivity Commission 2014*a*, see Gold Coast example, Supplement 7). In NSW, climate change considerations are required to be incorporated into flood studies and management studies for a 'reasonable period of time' (given as twenty years). Increased planning levels are suggested as an option for managing increased flood risk over time, but levels more conservative than 1 in 100 AEP are discouraged and standard freeboard (an added safety margin), is expected to buffer changes in risk over the twenty-year period (NSW Government 2005). As new development should be expected to last considerably longer than twenty years, this policy seems inadequate and is likely to create ongoing demand for flood mitigation infrastructure.

The use of the 1 in 100 AEP as a standard for development planning and levee height has been strongly challenged in the USA, where it originated (Wenger *et al.* 2012). There, approximately one third of flood losses are incurred outside the 1 in 100 AEP mapped floodplain (Galloway *et al.* 2006). The prospect that flood mitigation infrastructure may become increasingly vulnerable to extreme events has given rise to many different levee-related strategies globally. In China and the Netherlands, strengthening of key levees forms part of climate change strategy (P.R.C. 2007; Deltacommissie 2008). Similarly, USA flood reviews advocate levee heights up to 1 in 500 AEP, to provide an added margin of safety in densely populated areas (ILPRC 2006; Galloway *et al.* 2007; NCLS 2009). In Australia, raising levee height is not always feasible due to cost or catchment characteristics, especially in coastal catchments which are generally steeper. However, many of Australia's inland floodplains are unconstrained, with the difference between a 1 in 100 AEP flood and a probable maximum flood measured in centimetres (BTRE 2002). Arguably, in these circumstances it would take little to build a levee robust enough to cope with any climate change uncertainty.

Other overseas strategies include relocation, flood compatible land use, integrated water resource management, broad-scale flood management, and increasing the water storage capacity of the landscape through measures such as levee realignment and reconnection of rivers to lakes (Wenger 2015*b*). Policies in these countries suggest a change of mindset and values and are often accompanied by changes in organisational arrangements and skills. Engineering is not automatically viewed as the most economical solution of choice, and other considerations are increasingly valued (Huitema 2002; ASFPM 2008; te Boekhorst *et al.* 2010). Such changes in mindset are characteristic of 'transformational' adaptation.

To a greater or lesser degree depending on state policy, similar strategies are used in Australia, but the economic superiority of levees over other measures is never seriously challenged. For example, NSW finds levees 'tried and true' and 'frequently the most economically attractive measure' (NSW Government 2005), while the Productivity Commission reiterates several times that relocation is 'very expensive and only viable in exceptional circumstances' (Productivity Commission 2014*a*). However, the voluntary relocation of 120 households at Grantham, QLD following the 2011 floods was arguably no greater than the upfront cost of some levee systems and the sum was recouped two years later in avoided damages (Wenger 2014). The Commission's assertion is contradicted by studies in the USA that find repeat flood damage can exceed property value several times over (NWF 1998); the perception of the cost of relocation depends more on who pays for repeat damages, the public or the private purse.

3.5 Adverse impacts of levees

External impacts of structural mitigation have been documented worldwide, including higher flood risks for people elsewhere in the catchment and the degradation of riparian habitats. Some examples include: loss of coastal marshland at a rate of 60km^2 per year in Louisiana, USA, due to damming and restriction of sediment to leveed channels which exposes New Orleans to storm surge (Alexander 2013); increased wildfire, reduced water quality, loss of biodiversity and changing ecological communities due to wetland drainage and levee use in the Everglades, USA (UNFCCC 2006; Walker and Salt 2006); and channelling silt into the Yangtze River's lakes in China, reducing flood storage and discharge capacity and increasing flood depth and frequency (Yin and Li 2001; Zhang *et al.* 2006).

Adverse environmental impacts of levees received little attention in Queensland and Victoria's post-2011 flood reviews. However, 'cumulative and environmental impacts' were included as a key issue in the former Department of Sustainability and Environment's[46] (DSE) submission to the Victorian Inquiry into Flood Mitigation Infrastructure (ENRC Inquiry). Levees isolate rivers from their floodplains and reduce the frequency of flooding for riparian forests causing dieback and decline of forest dependent biota. Reduced flood frequency also diminishes groundwater replenishment and changes nutrient balances. These effects are likely to be compounded by prolonged droughts associated with climate change (Natural Resources Commission 2009; DSE 2012*a*).

Arguably, the most significant impact on ecosystems is caused by landscape-scale rural levees and irrigation infrastructure rather than town levees. Irrigation channels are usually embanked and often serve as *de facto* levee banks in rural landscapes (Parliament of Victoria 2012; QFCI 2012; Wenger *et al.* 2013). The impact of irrigation infrastructure can be enormous. Two rare studies of the Lowbidgee floodplain in the Murrumbidgee River Catchment (Kingsford and Thomas 2004) and the Macquarie Floodplain (Steinfeld and Kingsford 2013) quantify the amount of embankment and its effect on ecosystems. In the Lowbidgee, 2,145 km of levee banks and 394 km of artificial embanked channels was associated with 76% loss or degradation of wetlands and reduced waterbird abundance and species. The Macquarie floodplain study found a loss of lateral connectivity affecting flood control, water filtration and the species composition of wetlands. Roughly a third of the 55 sites studied demonstrated a high mortality of flood-dependent forest trees. Recently enacted Queensland legislation specifically excludes irrigation infrastructure from its definition of levees (see Table 6.2*c*). The extent and impact of

[46] Following several restructures, now the Department of the Environment, Land, Water and Planning.

levees on both flood behaviour and ecosystem services could be underestimated if irrigation infrastructure is not taken into account.

Levee maintenance also has adverse impacts. Best practice maintenance requires removal of trees and shrubs from levees, and from a strip of land beyond the levee toe between 3 and 5 metres wide on each side. This effectively prevents the re-establishment of riparian habitat within the reduced floodplain (between the river and the levee). Goondiwindi's policy discourages tree planting within 20 metres of levee banks (Goondiwindi Regional Council 2011). Guidelines vary but may require levees and vegetation management zones to be turfed, fertilized, mown and treated with herbicide to prevent the establishment of woody plants (State Government of Victoria 2002; USACE 2006; CIRIA 2013). Such requirements are not compatible with water quality protection or the retention of healthy riparian vegetation. Problems are particularly acute where levees are located close to riverbanks. Modern best practice advocates that levees be set back from riverbanks where feasible (CIRIA 2013; Queensland Government 2014*a*). However, many levees predate this wisdom. There are also contemporary examples where ideal alignment is not accepted by local decision makers (Moorhouse *et al.* 2014), or of emergency levees being constructed during floods, in the absence of flood studies or engineering design, that are later permanently retained by local governments (Parliament of Victoria 2012). Even where best practice is followed, options for levee setback may be limited by past decisions to build towns close to rivers.

Many local flood mitigation solutions, including levees and associated works such as channel modification and vegetation clearance confine floodwater, reduce natural flood storage and worsen flooding catchment-wide. This can increase flood peaks and water velocity downstream (Jones 2000; Rutherfurd *et al.* 2007). Interviews with Australian flood professionals conducted following the 2011 floods suggest that flood velocity is one of the most significant causes of damage to public infrastructure (Wenger *et al.* 2013). The degree of damage to structures is usually estimated using depth (stage-damage curves), but the effect of velocity on damage is recognised, and both factors are commonly used as the hydraulic basis for determining flood hazard to people and property (NSW Government 2005, Appendix L).

The Queensland Floods Commission of Inquiry (QFCI) heard many claims of private levees increasing flood effects for neighbours. This was a significant factor in Queensland's decision to introduce levee regulation (QFCI 2012; Queensland Government 2013*c*). Unneighbourly behaviour has also been reported between Victoria and New South Wales, with long-standing disputes concerning levees pushing floodwaters across state borders. The ENRC Inquiry heard that levees on the NSW side of the Murray were higher than on the Victorian side and had no permit conditions regulating height. River regulation infrastructure was also used to prevent 2011 floodwaters from crossing into NSW (DSE, 2012*a*; Parliament of Victoria, 2012).

3.6 Catchment management and cumulative effects

Because water management is associated with negative externalities, water governance theorists often support catchment or basin-wide management of water resources based on natural, topographic rather than administrative boundaries. However, catchment-based management of flooding can be problematic in Australia, where flood mitigation is generally viewed as a local government responsibility and decisions are taken locally.

Concepts about what constitutes a catchment can vary according to jurisdiction and agency and definitions vary. For example:

> "an area which, through run-off or percolation, contributes to the water in a stream or stream system" (Victorian *Catchment and Land Protection Act 1994:* S. 3(1)).
>
> "an extent of land drained by a particular stream or river" (State of NSW 2010: 33).
>
> "the land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location" (NSW Government 2005: 19).

While the first two definitions incorporate a whole stream or stream system, the last ends at a 'particular site', which may equate to a town boundary, even though the stream may extend beyond this point. The 'level' of catchment considered may also vary, from the small sub-catchment of an upper tributary, through to a major drainage basin. This influences the extent to which impacts can be assessed.

Some suggest that the term 'catchment', far from being defined in purely hydrological terms, is actually a social construct (Blomquist and Schlager 2005; Daniell and Barreteau 2014); the level of hydrological unit considered in studies and plans relates to what is politically or socially relevant, and 'as in changes in electoral boundaries for political voting', this can be manipulated as a means of changing the probability of outcomes (Daniell and Barreteau 2014).

In Australia, different hydrological levels may be used depending on purpose. For example, priorities may be assessed regionally using consistent risk assessment methodology (State of Victoria 2014*b*). Another common expectation is for local floodplain management plans to consider catchment plan objectives, with a focus on ensuring that flood mitigation does not compromise future development opportunities (NSW Government 2005), although in practice, flood studies and plans do not always reference catchment plans. At the local level, studies assess impacts of proposed mitigation on flood behaviour for nearby existing development and decision-making prioritises local concerns. There may be less consideration of regional impacts on ecosystems that rely on periodic flooding; on resources such as soil, water quality; or on broader catchment industries such as fisheries or tourism.

Also a concern is whether impacts are assessed on a cumulative or a project-by-project basis. The DSE reports that 'the full cumulative impacts of levees in Victoria are not well understood' and recommends that for any new levees, regional consequences be considered (DSE 2012*a*). Updated regional floodplain management strategies (State of Victoria 2014*b*) are a potential vehicle for addressing this. External effects of levees may significantly offset local levee benefits and it is important to be able to assess cumulative effects of levees and levee-like structures across catchments on flood behaviour and environmental assets, to identify thresholds and set limits.

In NSW, cumulative effects of development on flood risk, and emergency services are assessed in floodplain risk management studies (NSW Government 2005, Appendix G). There are no guidelines regarding cumulative impacts assessment methodology, although Appendix L suggests the aim should be 'to assess the suitability of future types of land use and development' through categorisation of flood prone land. For this, cumulative impacts of 'ultimate' development (as opposed to individual developments) are expected to be assessed. Twenty years into the future is suggested as a reasonable timeframe and floodplain risk management committees are also expected to consider broad-scale catchment issues.

A strategic, regional assessment of cumulative impacts is advocated by the recently revised national guide to managing floodplains (AGD 2013), which concurs with review findings by Duinker *et al.* (2012) on cumulative effects assessment methodology. Australian cumulative impacts studies generally take 'existing' flood hazard (assessed during the flood study) as their baseline. This does not necessarily establish the degree of change already sustained by the system (for example, the total loss of flood storage capacity from its 'natural' state) but it incorporates the cumulative effect of past development. Changes in flood risk are then assessed against development anticipated in local or regional plans, and for proposed flood mitigation options. Thresholds are identified in terms of whether or not increases in flood hazard are 'acceptable' or can be managed. Moving baselines and acceptance of 'insignificant' increases could lead to incremental change.

Some NSW councils criticise current arrangements and suggest they do not lead to sustainable outcomes. Sellers and Mooney (2012) point to a lack of integration between floodplain management (which requires consideration of flood risk up to probable maximum flood) and development planning policies (restricting councils' ability to impose development controls above the 1 in 100 AEP event). This is a concern as inadequate development controls could lead to future demand for levees, especially if risks change. Others argue that under the cover of participatory processes, arrangements force communities to 'choose' sub-optimal solutions due to lack of funding, with consequences for intergenerational equity and the environment (Pang and Gordon 2004).

In Queensland, recent development policy revisions require that cumulative increase in the severity of natural hazards be avoided, in both levee code guidelines for assessable development and state planning policy for planning schemes (Queensland Government 2014*a*; Queensland Government 2014*c*). Queensland provisions assess individual development applications rather than the more strategic approach intended by NSW.

Attempts have been made, especially in NSW, to address the adverse impacts of rural levees and irrigation structures (NSW Government 2002). In the Clarence Valley near Grafton, NSW, drainage systems, flood levees and flood-gated watercourses were constructed during the 1960s and 1970s to mitigate flood. These measures exposed acid sulphate soils, reduced water quality, caused fish kills and biodiversity loss. The Clarence Floodplain Project was established in 1997 to reverse some of these problems and since then wetlands have been restored and more than 200 km of waterways have been opened up with the active cooperation of around 270 landholders. This has not only improved habitat and water quality but has increased the productivity of agriculture and fisheries (Smith 2011; Clarence Valley Council 2013*b*).

Reversing past impacts can also be integrated into state-wide initiatives. For example, the NSW Government aims to rectify environmental connectivity issues and hydraulic problems on a catchment level through 'rural floodplain management plans' (NSW Government 2002; NSW Government 2014). The program is currently transitioning to 'valley-wide floodplain management plans', as part of the National Water Initiative healthy floodplains project, which aims to restore floodplain connectivity in its second phase through modification or removal of works[47]. To date, such attempts have proved challenging. Activities have largely been confined to *unauthorised* structures, which may be licensed following modification. Modification of *approved* structures, which may involve amendment of licence conditions, depends on negotiation with landholders and funding availability, which is often lacking. Most landholder actions in the Edmund-Wakool plan are footnoted 'modifications to these approved works are subject to funding options, further investigation and landholder consultation' (NSW Government 2011).

[47] Phase 2 has not yet begun and progression to this phase is subject to review under the terms of the water management partnership agreement between the Commonwealth and New South Wales.

3.7 Levee safety

Levees are designed to protect property rather than lives but they nevertheless affect safety. In some cases they buy time to evacuate. More problematic is the effect that levees have on flood behaviour and human response.

Australian flood reviews report a number of levee safety issues. In the context of emergency services, levees can impede flood intelligence and the ability to predict flood behaviour such as movement and depth. This is particularly the case where temporary levees are constructed or where reliability is doubtful due to inadequate maintenance. During Victoria's 2010-11 floods, unauthorised levees sometimes increased flood risks by reducing the flood predictability for emergency managers. Such levees are also less likely to be built to engineering standards and are more likely to fail. Where temporary levees are used they need to be planned in advance and incorporated into emergency management frameworks (Comrie 2011; DSE 2012*a*; Parliament of Victoria 2012).

Another way in which levees compromise safety is by reducing risk awareness among those protected. Because levees successfully keep out small floods, over time people come to believe they are 'protected', while at the same time, their experience about what to do in a flood drops. In the event of breach, this not only threatens personal safety, but is also likely to result in higher damages (Tobin 1995; BTRE 2002). This has been found even in the Netherlands, where floods and dykes form part of national identity (Bezuyen *et al.* 1998).

The Nyngan floods (NSW 1990) are often seen as a turning point in the flood management of levee-protected towns in Australia. Nyngan's levees were built to withstand the flood of record, experienced in 1976. The town's flood strategy relied entirely on levees. In 1990, floodwaters overtopped the levee and broke through temporary sandbags placed to augment levee height. Lack of preparation, including failure to raise assets, meant that damages were high. Moreover, failure to evacuate before roads were cut resulted in an expensive aerial evacuation operation (Keys and Campbell 1991). The Nyngan floods engendered awareness of the limitations of levees and the need for contingency planning.

Despite Nyngan's example, poor flood preparation continues to be a problem in communities protected by levees. This includes resistance to evacuation by communities whose levees are threatened by overtopping. In Grafton (2001) only 10% of the population evacuated (Pfister 2002), while in Maitland (2007), 17.5% registered as evacuees (Evans *et al.* 2007). Queensland's post 2010-11 flood inquiry also provides evidence of levees reducing preparedness in

Goondiwindi[48], finding that authorities did not develop a staged evacuation plan based on water level triggers because they ‘did not think the flood would breach Goondiwindi’s levee banks’. In the event, the town’s 11 metre levee held against a record peak of 10.64 metres (BOM 2014; QFCI 2011).

Improving community education is often suggested as a remedy to address reduced flood experience and the flood-prone town of Lismore provides an example of a comprehensive community education program (Lismore City Council 2014). Lismore floods every four years on average. 2005 saw the completion of the central town levee to 1 in 10 AEP design height, while South Lismore has had levee protection since 1975. An advantage of the levees from the point of view of safety is that they increase warning times and the length of time evacuation routes can remain open. However, as reduced flood experience is a significant concern, and there has been considerable investment in community education.

While community education is vital to improve resilient behaviour in an emergency, faith in the effectiveness of such measures should not be unrealistic. Lismore’s flood risks are high and its education program is extensive. In parts of central Lismore, a 1 in 100 AEP flood may result in water depths of 3.4 metres and velocity of 1.4 m/s, with floodwaters rising 1.4 metres per hour (Lismore City Council 2014). Wood *et al*. (2010) suggest that ‘anyone trapped on the floodplain [in a severe flood] would probably perish’. However, they report that it has proved hard to maintain community attendance at flood awareness activities. In another study, a post-flood survey following Lismore’s 2005 floods suggests that education programs influenced only 32% of people in their decision making during the floods. While evacuation rates were better than in some places, the majority chose to remain (Opper *et al.* 2006). Community education programs cannot be relied upon to ensure safety in the event of levee failure.

3.8 Evidence of levees reducing adaptive behaviour

Levees are frequently associated with ‘renewed confidence’, for example, at Gympie and Charleville (Bligh 2011; Aurecon 2013). ‘Renewed confidence’ has a positive ring, but in this context it means that people have the confidence to continue to live, work and build in flood hazard areas. This may prevent alternative scenarios, in which an old flood-prone town centre is gradually usurped by new development on higher ground and the pricing of older areas (and their insurance premiums) reflect their true flood-prone value, over time becoming more affordable for voluntary purchase.

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[48] Goondiwindi participated in other flood preparedness activities, including a simulated emergency response exercise organised by Emergency Management Queensland prior to the floods (QFCI, 2011:120). At the time of the floods it was among the few local councils that had local laws concerning levees (QFCI 2012).

There is some evidence to suggest that levees inhibit the implementation of alternative strategies that are arguably more adaptive in the longer term, such as movement out of hazardous areas and flood-resilient building design (Reisinger *et al.* 2014). Lismore has levees in South Lismore and Central Lismore (completed in 1975 and 2005 respectively). Strategies in Lismore's Floodplain Risk Management Plan also include house raising and voluntary purchase in high risk areas. In the past Lismore's house raising activities have been impressive, and Smith (1998) reported that over 95% of residences within the 1 in 100 AEP floodplain had been raised. The Council also boasts one of the oldest voluntary house purchase programs in NSW, with an average of two houses removed from the floodplain each year between 1954 and 1997. However, in recent years the Council has proved reluctant to allocate funding towards both of these activities (Wood *et al.* 2010; Lismore City Council 2014). The reason for this is not clear. Although financial considerations appear to be an element, references cite 'priority' rather than 'affordability' as the reason, and Lismore's 2014 Floodplain Risk Management Plan views the purchase of one to two houses per year as financially feasible. It is possible that by reducing frequent 'nuisance flooding', levees have lowered the priority and immediate need for these activities.

Reduced flood frequency may also reduce the imperative for communities and individuals to mitigate, a form of maladaptation (Barnett and O'Neill 2010). Planning schemes may not identify land within levees as being floodprone; flood-related planning controls used elsewhere on the floodplain may not apply (e.g., State Government of Victoria 2014*b*). In Charleville, there are indications that the town levee, providing protection to roughly 1 in 50 AEP (Patterson *et al.* 2012), may have resulted in a regression of building standards to on-slab instead of elevated buildings (Keogh *et al.* 2011). South Lismore has had an (estimated) 1 in 10 AEP levee protection since 1975, and in recent decades many raised homes have been built-in underneath, including bricked-in living space. Given that the difference between average pre-levee flood frequency (1 in 4 AEP) and post-levee frequency (1 in 10 AEP) is not great, further studies on the relationship between flood frequency and adaptive/regressive behaviour might be worthwhile.

3.9 Levee Regulation and Inquiry Recommendations

Widespread flooding in eastern Australia 2010-11 resulted in the appraisal of flood mitigation infrastructure and rapid changes in legislative provisions in several states.

3.9.1 Victoria

Victoria's Inquiry into Flood Mitigation Infrastructure found that lack of clear levee ownership and responsibility for levees was a key concern for levee maintenance, particularly for rural levees on public land. Other concerns included liability for public managers in the event of levee failure, maintenance financing, processes for removing illegal levees and the integration of levees (including temporary levees) into emergency planning. Assessment of levees built on public land was recommended to determine their regional benefit. Of particular note, the inquiry recommended that levees on public land identified as ‘low priority’ (using cost benefit analysis) be allowed to disintegrate should beneficiaries be unwilling to fund maintenance (Parliament of Victoria 2012). This remarkable recommendation has been accepted by the Victorian Government and will allow the eventual restoration of many floodplains (State of Victoria 2013*b*; State of Victoria 2014*b*). The Victorian government is currently updating the Victorian Floodplain Management Strategy and the Water Act 1989 to reflect changes, including the application of the ‘beneficiary pays’ principle to maintenance arrangements (see Table 6.2*a*[49]).

3.9.2 New South Wales

In NSW, inadequate maintenance of levees has long been an issue and a review of urban levees is currently taking place to help improve maintenance arrangements and to improve information about levee design and reliability for emergency services (NSW Government 2013*a*).

NSW floodplain management is guided by processes outlined in the *Floodplain Development Manual 2005*. In practice, approval provisions largely depend on whether levees are urban or rural. Urban levees are generally covered by approval mechanisms under the *Environmental Planning and Assessment Act 1979*. The *Water Act 1912* governs most rural levee approvals (‘controlled works’) and floodplain management plans guide approval conditions in designated floodplains.

‘Controlled works’ approvals are currently transitioning to ‘flood works’ under the *Water Management Act 2000*. ‘Controlled works’ and ‘flood works’ are broadly defined. Under the new Act, anything that can interrupt the flow of water or distribution of floodwater is covered regardless of purpose, thus including levee-like structures[50].

Flood works within town boundaries will be exempt from approval under the *Water Management Act 2000* [51]; environmental assessment under Part 5 of the *Environmental Planning and Assessment Act 1979* will therefore not apply. Environmental assessment under Part 4 of the Act continues to apply, but only if a planning instrument (for example, a *Local*

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[49] Supplementary information relating to tables is available on the BNHCRC website at: http://www.bnhcrc.com.au/research/economics-policy-and-decision-making/1067

[50] Exemptions to ‘water supply works’ in the *Water Management (General) Regulation 2011* apply.

[51] This exemption does not include controlled activities, including specified activities in on or under waterfront land (within 40 metres of its bank). The *Water Management (General) Regulation 2011* includes exemptions (clauses 36-40; Part 2 of Schedule 5) and there is no list of activities to which it specifically applies.

Environmental Plan), identifies flood mitigation works as 'designated development'. In practice, this is unlikely to weaken provisions for environmental assessment given that the administrative processes, including those in the *Floodplain Development Manual* and grants applications require environmental assessment. However, there are content differences between different forms of environmental assessment and not all require cumulative effects assessment (see Table 6.2*b*).

Table 6.2*a*: Legislation and administrative provisions for levees in Victoria.

ISSUE	PROVISIONS
Levee database	The State Government maintains a GIS database that includes data for both levees and earthworks where the primary function is not flood mitigation.
Levee legislation & regulations	Most urban levees are subject to water management scheme provisions under the *Water Act 1989*. Private levees and earthworks require permits in accordance with *Victoria Planning Provisions* and local government planning schemes.
Levee Guidance	*Levee Design Construction and Maintenance 2002* (being updated) provides guidance and is not a legal requirement. The draft *Victorian Floodplain Management Strategy* (VFMS) provides a framework for flood management. It anticipates the preparation of management guidelines for flood mitigation infrastructure.
Consideration of climate change	Revised *Australian Rainfall and Runoff* (AR&R) guidelines are expected to address climate change concerns. Development controls are generally limited to the 1:100 ARI floodplain which may be inadequate to address future threats.
Regulation of levee-like structures	Irrigation licensing is through the *Water Act 1989*. Licence conditions can relate to environmental protection and natural drainage regimes but potential flood impacts are not considered. *Irrigation and drainage plans* are sometimes required. These need to be approved and contain information on location and specifications of irrigation works. Private levees and earthworks also require permits in accordance with *Victoria Planning Provisions* and local government planning schemes. Decision guidelines in flood prone areas cover the effect on flood behaviour and environmental impacts.
Catchment planning and cumulative effects assessment	Catchment Management Authorities (CMAs) are appointed under the *Catchment and Land Protection Act 1994*. CMAs are authorised by the *Water Act 1989* to prepare *regional floodplain management strategies,* detailing catchment characteristics and programs for flood damage prevention and mitigation. These are being updated to implement the *VFMS*. Regional priorities will be assessed through Victoria's *Rapid Appraisal Method (RAM) for Floodplain Management*, soon to be updated. Regional growth plans, regional strategic plans, regional catchment management strategies and regional waterway strategies also have flood-related content. Ministerial Guidelines under the *Environmental Effects Act 1978* promote cumulative effects assessment as a desirable element of environmental effects statements. However, the application of the Act is limited. Guidelines do not offer a cumulative effects methodology. Floodplain management plans assess the offsite impacts of proposed measures. However, regional cumulative effects assessment of levees and levee-like structures on flood behaviour and the environment currently seems lacking.
Programs and grants	Recent levee funding has been provided through the *FloodZoom* program, the *Natural Disaster Resilience Grants Scheme* and the *Regional Growth Fund*. Assessment criteria and information about the types of projects eligible are vague and are sometimes not readily available. Lists of funded projects are sometimes lacking. Programs focus on flood information, flood warning and structural mitigation.
Development controls behind levees	Local governments are responsible for controlling development in the most low-lying areas behind levees. Evidence from regional growth plans and planning schemes indicates that leveed areas are a focus for development infill and expansion.

Table 6.2*b*: Legislation and administrative provisions for levees in New South Wales.

ISSUE	PROVISIONS
Levee database	An urban levee database is under development. Information on rural earthworks is kept on a controlled works database and files.
Levee legislation & regulations	The *Water Act 1912* and the *Water Management Act 2000* control the licensing of controlled works (including flood control works that are not within town boundaries), with environmental assessment requirements as per the *Environmental Planning and Assessment Act 1979*. Works within town boundaries are assessed under *EP&A Act* provisions if identified as designated development (e.g., by local government). Acts also provide for the development of floodplain management plans, which are used to assess whether or not proposed development is complying or requires approval.
Levee Guidance	*Floodplain Development Manual* (2005), authorised by s733 (5)(a) of the *Local Government Act 1993*, provides a floodplain risk management framework including guidance on advantages and disadvantages of using levees and how to assess this option (and others) using an option assessment matrix.
Consideration of climate change	The *Floodplain Development Manual* recommends the use of AR&R in flood studies. *Floodplain Risk Management Guidelines* cover climate change considerations and the use of levees. *Planning Circular PS 07-003* limits the use of development controls above 1 in 100 AEP, which may result in greater future demand for structural mitigation.
Regulation of levee-like structures	Irrigation channel embankments and ring tanks are regulated through the *Water Act 1912* (to be repealed) and the *Water Management Act 2000*. Approvals require information to enable assessment of environmental impacts and changes in water flows, including information about dimensions of works and location in relation to water bodies.
Catchment planning and cumulative effects assessment	The *Floodplain Development Manual* expects the consideration of catchment-wide issues and development trends but does not require flood studies or management studies to cover entire catchments. Floodplain risk management studies and options analysis are very much locally-driven, which could limit the consideration of measures requiring broad-scale implementation beyond municipal boundaries. The Manual requires consideration of cumulative and catchment-wide impacts of proposed development but does not provide cumulative impacts methodology. There must be no ‘significant impact’ on other properties but ‘significant’ is not defined and the Manual appears to take ‘now’ as the (potentially mobile) baseline. Together, these factors could enable incremental change. Cumulative impact assessment is not an explicit requirement of Part 4 of the *Environmental Planning and Assessment Act 1979* (used to assess urban levees). Rural floodplain management plans calculate cumulative impacts and impose limits on redistribution of flows for licencing approvals but baselines may be reset to ‘now’ when plans are renewed.
Programs and grants	Grants are available through the Floodplain Risk Management Grants Scheme (jointly funded by the federal Natural Disaster Resilience Program), and the NSW Floodplain Management Program. Funding proposals are expected to adhere to Floodplain Development Manual processes and a variety of measures is eligible.
Development controls behind levees	Development controls behind levees 'should' be considered by local governments (NSW Government 2005).

3.9.3 Queensland

Queensland's Floods Commission of Inquiry heard many instances of levees and irrigation infrastructure causing more severe flooding elsewhere. Prior to the 2011 floods, levees were entirely unregulated by the State Government. Only seven local governments had local laws concerning levees and most were repealed shortly after. Inquiry recommendations included a need to regulate levees on a state-wide basis, using consistent assessment processes and criteria.

The Commission emphasised the potential for levees to have catchment-wide impacts and recommended that assessment consider benefits and adverse impacts on the catchment, landholders and communities. It also recommended that the risk of levee failure be assessed and consideration be given to mitigating adverse levee impacts through land planning and emergency management or structural measures (QFCI 2012). The lack of a catchment planning was also observed by the Queensland Reconstruction Authority which noted the 'current' case-by-case, individual development approval approach to floodplain management. It advocated strategic, sub-basin level coordination of flood management through Regional Planning Committees (QRA 2012*b*). However, recently published technical manuals make no reference to a role for Regional Planning Committees and the Queensland Government position is that responsibility for flood management should rest with local governments (DSDIP 2014).

The Queensland Government accepted the Inquiry recommendations and introduced levee regulation through amendments to the *Water Act 2000 (Qld).* The Act requires development approval under the *Sustainable Planning Act 2009 (Qld)*. Decision makers are expected to consider the impact of any new levee or levee modification on off-site on overland flow water, the catchment, landholders, communities and land planning and emergency procedures (State of Queensland 2013). The Act excludes levee-like structures from the legal definition of a levee, which has the potential to provide a significant loophole for landholders to continue building earthworks that can serve the dual purpose of retaining water on their land or keeping floodwaters out. The Act is supported by assessment codes and guidelines (see Table 6.2*c*).

Table 6.2*c*: Legislation and administrative provisions for levees in Queensland.

ISSUE	PROVISIONS
Levee database	Currently no levee database. Information relating to irrigation licences must be retained in accordance with the *Public Records Act 2002* and may be held on departmental databases.
Levee legislation & regulations	*Water Act 2000* and *Water Regulation 2002* require new levees to be assessed, and provide parameters for different levels of assessment. Assessment is carried out under the *Sustainable Planning Act 2009*, using *State Development Assessment Provisions*.
Levee Guidance	Queensland has recently developed comprehensive levee guidelines (category 1 self-assessable; categories 2 & 3 *Integrated Development Assessment System* (IDAS) code assessment; and category 3 state impact assessment).
Consideration of climate change	*Increasing Queensland's Resilience to Inland Flooding in a Changing Climate* provides interim climate change factors, pending the revision of AR&R guidelines which are expected to incorporate climate change. A defined flood level is no longer prescribed in *State Planning Policy* or guidelines. Depending on how well risk assessment is applied, this may facilitate the development of flood prone land.
Regulation of levee-like structures	The *Water Act 2000* levee definition excludes levee-like structures. The Act governs licensing relating to the take or interference with water, but this is only regulated in certain circumstances. Assessment codes under the *Sustainable Planning Act 2009* and *State Development Assessment Provisions* (including water diversion, harvesting and irrigation codes) require information about the area to be irrigated and distance from watercourses, but do not mention embankments or impact on flood behaviour.
Catchment planning and cumulative effects assessment	Under the *Water Act 2000*, the impacts of new levees on catchments and catchment landholders need to be assessed. Level of assessment is determined by impacts to off-property structures, which could limit consideration of environmental and cumulative effects. Levee guidelines expect assessment of the contribution of a levee to cumulative impacts on a catchment or sub-catchment (no methodology offered). Wording suggests a project-by-project approach. *State Planning Policy (SPP)* and its *Guideline*, require planning schemes to avoid cumulative increase in the severity of natural hazards. Future development scenarios are expected to be considered by *SPP Technical Manuals* which affirm the local level as the most appropriate for guiding processes. This does not support earlier Queensland Reconstruction Authority recommendations for oversight by regional planning committees.
Programs and grants	*Royalties for Regions,* the *Local Government Floods Response Subsidy* and the *Natural Disaster Resilience Program* provide funding for mitigation infrastructure. Some options are expressly ineligible (e.g., house raising), and it is not clear what funding support is available if such options are found to be more appropriate than structural measures.
Development controls behind levees	Intensified land use is appropriate if risks have been mitigated 'to an acceptable or tolerable level' (Queensland Government, 2014*c*). This is likely to increase potential damages.

4. Conclusion

A review of levee use in Australia reveals a continuing appetite for levees, despite evidence of high upfront and ongoing costs, safety issues and adverse impacts on flood behaviour and the environment. This can be attributed to significant financial incentives for levee building, such as lower insurance costs and development gains.

Little guidance is given at national or state levels about the types of measures that would enable Australia to best adapt to future threats. Instead, primary responsibility for flood mitigation is devolved to the local level, which can limit consideration of broader regional issues and cumulative impacts. Moreover, management options available to local governments are limited. State programs offer little support, and sometimes render ineligible, measures such as relocation or individual property-based measures, which are associated with longer term transformational adaptation. State development policies and legislation may also limit the ability of local governments to apply flood-related development controls and the period of time over which climate change can be considered. This is likely to fuel future demand for structural protection.

Evidence from the three states studied indicates that levees provide a focal point for future development growth. Where land is protected by levees, development controls may not apply and adaptation by individuals tends to regress. This 'all or nothing' approach means that consequences will be greater when flood defences are overwhelmed, which is likely to happen more frequently as a result of climate instability. The more development built to non-flood compatible standards in vulnerable locations, the more costly it will be to change to a different strategy if levees ultimately prove inadequate.

With rare flood events likely to occur more frequently, Australia needs to consider which type of measures will best provide for long term adaptation. Levees are an incremental adaptation measure that extend the amount of time that 'business as usual' can occur. As such, they should only be considered a temporary solution. Long term adjustments also need to be planned and funded, with appropriate incentives and decision-making structures.

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Appendix 6.1: documents checked for relevance to levees

Documents surveyed include: legislation, regulations, guidelines, policies, strategies, programs and assessment/approval documents from Victoria, NSW and Queensland. A small number of Commonwealth documents were also checked, especially where cross-referenced by state documents. The survey did not include state flood review and inquiry reports (post 2010-2011) or Commonwealth disaster resilience provisions. These were analysed separately and where relevant are cited in the main text.

Some documents are specific to levees. However others are less directly linked. For example, many concern flood-related planning legislation (as strong planning controls may prevent the future need for levees). Provisions relating to “levee-like structures” also required a broader search. To restrict scope, provisions checked were generally limited to embanked channels for irrigation delivery, storage and drainage. Transport infrastructure was not specifically investigated. However, neither was it deliberately excluded.

Notes taken about these documents, as well as extended tables that synthesize results, can be found on the Bushfire and Natural Hazards Cooperative Research Council website at:

www.bnhcrc.com.au/wenger/supp/table (supplementary tables); and

www.bnhcrc.com.au/wenger/supp/docs_checked (document analysis).

Table 6.5: Victoria.

#	Document	Version
1	**Water Act 1989**	1 July 2014
2	‘Floodplain Management’ DEPI website: http://www.depi.vic.gov.au/water/Floods-and-floodplains/floodplain-management	[accessed Dec 2014]
3	Victorian Environmental Water Holder (VEWH): http://www.vewh.vic.gov.au/about-us	[accessed 5 Feb 2015]
4	**Catchment and Land Protection Act 1994**	1 Oct 2014
5	**Environment Protection Act 1970**	13 Nov 2014
6	**Environment Protection (Resource Efficiency) Act 2002**	18 June 2002
7	State Environment Protection Policy (Waters of Victoria)	4 June 2003
8	State Environment Protection Policy (Groundwaters of Victoria)	1997
9	Variation of state environment protection policy (Groundwaters of Victoria)	2002
10	**Environmental Effects Act 1978**	4 May 2012
11	Ministerial guidelines for assessment of environmental effects under the Environmental Effects Act 1978	June 2006
12	**Aboriginal Heritage Act 2006**	1 Jul 2014
13	Aboriginal Heritage Regulations 2007	13 Feb 2013
14	Practice Note 45: The Aboriginal Heritage Act 2006 and the planning permit process	Oct 2013
15	**Heritage Rivers Act 1992**	17 May 2012
16	**Heritage Act 1995**	1 July 2014

17	**Wildlife Act 1975**	17 Sept 2014
18	**Flora and Fauna Guarantee Act 1988**	1 Dec 2013
19	Victoria's Biodiversity: Directions in Management	1997
20	DEPI Flora and Fauna Guarantee Act 1988 Threatened List	Oct 2014
21	DSE Flora and Fauna Guarantee Act 1988 Processes List	July 2012
22	**National Parks Act 1975**	1 Sept 2014
23	**Forests Act 1958**	1 July 2014
24	**Conservation, Forests and Lands Act 1987**	1 July 2014
25	**Project Development and Construction Management Act 1994**	1 July 2014
26	**Building Act 1993**	15 Oct 2014
27	Building Regulations 2006	10 Feb 2015
28	Levee design, construction and maintenance technical guidelines	2002
29	Regional Directions for Irrigation Development: Regional Irrigation Development Guidelines Northern Victoria	July 2007
30	North Central Regional Irrigation Development Guidelines	June 2008
31	Goulburn-Murray Water Application for a Licence to Take and Use Surface Water and Operate Works (Unregulated)	nd
32	North Central catchment management authority: application for a permit to construct and operate works on a waterway	nd
33	Application for a Water-Use Licence or Water-Use Registration: Form 23	nd
34	Policy for managing take and use licences	2 Feb 2014
35	Improved flood protection for Kerang community (Media Release: Minister Peter Walsh): http://www.peterwalsh.org.au/_blog/Media_Releases/post/improved-flood-protection-for-kerang-community/ (accessed 26.2.2015)	Apr 24, 2014
36	Walsh opens upgraded Kerang levee (ABC News): http://www.abc.net.au/news/2014-04-25/walsh-opens-upgraded-kerang-levee/5411368 (accessed 26.6.2015)	25 Apr 2014
37	Announced Local Government Infrastructure Program Grants (2011-current): http://www.rdv.vic.gov.au/about-us/announced-funding/lgip (accessed 26.2.15)	1 Dec 2014
38	'Town levee works' in The Northern Times (reporter: Farrah Plummer): http://www.thenortherntimes.com.au/story/217373/town-levee-works/ (accessed 13/10/2014)	Apr 23, 2012
39	Post-flood interview with a Gannawarra Shire official [unpublished extract]	2012
40	2012 Flood Recovery Community Infrastructure Fund	Feb 2011
41	Floods Community Recovery Fund Funding Guideline for Community Organisations and Local Councils	Feb 2011
42	Reducing flood impacts for Victoria (media release: Minister Walsh): http://vic.liberal.org.au/News/MediaReleases.aspx?id=7131&title=Reducing%20flood%20impacts%20for%20Victoria (accessed 22 Nov 2013)	17 Oct 2013
43	Natural disaster resilience grants scheme – Victoria: applicant guidelines 2014-15	Aug 2014
44	Natural disaster resilience grants scheme – Victoria: application form 2014-15	Aug 2014
45	Emergency Risks in Victoria	Feb 2014
46	Rapid Appraisal Method (RAM) for Floodplain Management	May 2000
47	**Climate Change Act 2010**	8 Mar 2013
48	Climate Change Adaptation Plan	Mar 2013
49	Building a climate resilient Victoria: Victorian Climate Change Adaptation Plan progress report	2014

50	Victoria Flood Database update specification	Mar 2009
51	Gauntlett, I and Cawood, M. 2000. The Victorian Flood Data Transfer Project. Paper presented to the 40th Annual Conference of the Floodplain Managers Association	2000
52	Victorian Government's Response to the Environment and Natural Resources Committee Inquiry into Flood Mitigation Infrastructure in Victoria	Oct 2013
53	Victorian Emergency Management Reform White paper	Dec 2012
54	Draft Victorian Floodplain Management Strategy (VFMS)	2014
55	Victorian Waterway Management Strategy (VWMS)	Sept 2013
56	**Land Acquisition and Compensation Act 1986**	10 Nov 2014
57	**Crown Land (Reserves) Act 1978**	22 Sept 2014
58	**Land Act 1958**	22 Sept 2014
59	Riparian management Licences: recognising that Crown land water frontages are being managed to protect the riparian environment	2014
60	Crown land water frontage licences	2014
61	Managing Crown water frontages: for better farms and waterways	2014
62	**Local Government Act 1989**	15 Oct 2014
63	**Planning and Environment Act 1987**	10 Sept 2014
64	Victoria Planning Provisions User Guide	19 Sept 2014
 65 66 67 68	*State Planning Policy Framework (SPPF)* Floodplain management policy Climate change impacts: coastal inundation and erosion Catchment planning and management Water quality	 20.09.2010 04.07.2012 20.09.2010 20.09.2010
 69 70 71 72 73 74	*Local Planning Policy Framework (LPP)* Rural Living Zone Green Wedge Zone Green Wedge Zone A Rural Conservation Zone Farming Zone Rural Activity Zone	05.09.2013 (all)
 75 76 77 78 79	*Local Planning Policy Framework (LPP)* Urban Floodway Zone Floodway Overlay Land subject to inundation overlay Special Building overlay General provisions	 8.8.2010 15.09.2008 15.09.2008 15.09.2008 22.08.2014
80	Practice Note 12: Applying the flood provisions in planning schemes: a guide for councils	Nov 2012
81	Gannawarra Planning Scheme	19 Sept 2014
82	Gannawarra Planning Scheme – local provision: Rural Floodway Overlay Map No. 15RFO	03.10.2009
83	Gannawarra Planning Scheme – local provision: Land Subject to Inundation Overlay Map No. 15LSIO	03.10.2009
84	Planning application information checklist for Rural earthworks	1 Mar 2004
85	SPPF: Regional Planning Strategies and Principles Strategic Plans	30.05.2014
86	Gippsland Regional Growth Plan	May 2014
87	Loddon Mallee North Regional Growth Plan	May 2014
88	Gippsland Regional Strategic Plan	2010
89	Loddon Mallee Regional Strategic Plan Northern Region	2010
90	North Central Catchment Management Authority submission on the Draft Victorian Floodplain Management Strategy. Ref: NCCMA-63-37251	11 Aug 2014

[91]	[North Central Regional Floodplain Management Strategy]	[Out of date: not available]
92	North Central CMA Media Release: Draft Castlemaine, Campbells Creek and Chewton Flood Plan	Feb 2015
93	2013-19 North Central Regional Catchment Management Strategy	2013
94	2014-2022 North Central Waterway Strategy	2014

Table 6.6: New South Wales.

#	Document	Version
95	**Water Act 1912**	1 Jan 2014
96	**Water Management Act 2000**	4 July 2014
97	Water Management (General) Regulation 2011	25 July 2014
98	Application for approval for water supply works, and/or water use	Sept 2010
99	Application for Approval of a Controlled Work	Sept 2010
100	Application for a Surface Water Licence	Sept 2010
101	Application for a Surface Water Permit	Sept 2010
102	Application for a Groundwater Licence	Sept 2010
103	Application for an Authority for a Joint Water Supply Scheme	Sept 2010
104	Application for a Controlled Activity Approval for works on waterfront land	Sept 2012
105	Proposed changes to controlled works issued under part 8 of the Water Act 1912 - Frequently asked questions	Sept 2014
106	Floodplain Development Manual: the management of flood liable land	2005
107	Whites Creek Floodplain Risk Management Study and Plan	7 Dec 2012
108	Wingecarribee Shire Council Wingecarribee River Flood Study	Feb 2014
109	Hawkesbury Floodplain Risk Management Strategy and Plan	Dec 2012
110	Planning Circular PS 07-003: New Guideline and changes to section 117 direction and EP&A Regulation on flood prone land (Department of Planning)	31 Jan 2007
111	Floodplain Risk Management Guideline: Practical Consideration of Climate Change	25 Oct 2007
112	**Local Land Services Act 2013**	2 Jan 2014
113	Local Land Services Regulation 2014	1 Jan 2014
114	NSW Healthy Floodplains Project (online factsheet)	May 2013
115	Water management partnership agreement between the Commonwealth and New South Wales: Project schedule 4: Healthy Floodplains Project	11 Jan 2010
116	Floodplain Management Plan for the Gwydir Valley Floodplain 2015 Draft Order	Sept 2014
117	Draft Background document to the floodplain management plan for the Gwydir Valley Floodplain 2015	Sept 2014
118	An overview of floodplain management plans under the Water Management Act 2000	Aug 2014
119	Gwydir River : Lower Gingham Watercourse Floodplain Management Plan	2006
120	State Water Management Outcomes Plan Order 2002 No.1028 (NSW)	18 Dec 2002
121	Floodplain Management Plan: Murrumbidgee River Hay to Maude	April 2014
122	Floodplain Management Plan: Edward and Wakool Rivers Stage 1: Deniliquin to Moama–Moulamein Railway	Jan 2011
123	**Public Works and Procurement Act 1912**	24 Feb 2014
124	**Land Acquisition (Just Terms Compensation) Act 1991**	31 Jan 2011

125	**Environmental Planning and Assessment Act 1979**	25 July 2014
126	Environmental Planning and Assessment Regulation 2000	25 July 2014
127	Environmental Planning and Assessment Amendment (Flood Related Development Controls Information) Regulation 2007	16 Feb 2007
128	State environmental planning policy (infrastructure) 2007	23 Oct 2014
129	NSW Wetlands Policy	March 2010
130	State Environmental Planning Policy No 14—Coastal Wetlands	1 Oct 2011
131	State Environmental Planning Policy (Major Development) 2005 (NSW)	31 May 2014
132	State Environmental Planning Policy No 1—Development Standards	17 May 2002
133	State Environmental Planning Policy (Exempt and Complying Development Codes) 2008	18 July 2014
134	State Environmental Planning Policy No 33—Hazardous and Offensive Development	13 Mar 1992
135	Standard Instrument (Local Environmental Plans) Order 2006 No.155 (NSW), Local Environmental Plans, Regional Environmental Plans	15 Aug 2014
136	Standard Instrument—Principal Local Environmental Plan	15 Aug 2014
137	Model Local Provisions clause 7.3 – flood planning	Dec 2010
138	State Environmental Planning Policy (State and Regional Development) 2011	5 Sept 2014
139	What is State significant development and how are applications assessed and determined?	Feb 2012
140	**Local Government Act 1993**	4 July 2014
141	Media Release: Commissioner warns of severe penalties for constructing levees without approval	13 Mar 2012
142	**Native Vegetation Act 2003**	1 Jan 2014
143	**Threatened Species Conservation Act 1995**	17 Oct 2014
144	NSW 2021	nd [2012?]
145	**Fisheries Management Act 1994**	4 Nov 2014
146	Floodplain Management Programs Guidelines for Applicants	2014-15
147	Floodplain Management Program new works project ranking form 2014-15	2014-15
148	Work Plan - Investigation and Design Project [sample document]	2014-15
149	Work Plan - Floodplain Risk Management Study and Plan (FRMSP) [sample document]	2014-15
150	Work Plan - Flood Study [sample document]	2014-15
151	Funding Agreement for Financial Assistance under the 2012/13 Natural Disaster Resilience Program's Floodplain Risk Management Grants Scheme [sample document]	2014-15
152	Funding Agreement for Financial Assistance under the 2012/13 NSW Floodplain Management Program [sample document]	2014-15

Table 6.7: Queensland.

#	Document	Version
153	**Land, Water and Other Legislation Amendment Act 2013**	2013
154	Regulation of Levees in Queensland: Consultation Regulatory Impact Statement	2013
155	**Water Act 2000**	1 July 2014
156	Water Regulation 2002	4 July 2014
157	IDAS code for development applications for construction or modification of particular levees	4 July 2014
158	Self-assessable code for construction or modification of levees	2014

159	Guidelines for the construction or modification of category 1 levees	2014
160	Guidelines for the construction or modification of category 2 and 3 levees	2014
161	Queensland Building and Construction Commission Regulation 2003	1 July 2014
162	**Water Supply (Safety and Reliability) Act 2008**	21 May 2014
163	Manual for Assessing Consequence Categories and Hydraulic Performance of Structures	Nov 2013
164	**Environmental Protection Act 1994**	1 July 2014
165	Environmental Protection Regulation 2008	1 July 2014
166	Environmental Protection (Water) Policy 2009	6 Dec 2013
167	Generic draft terms of reference for an environmental impact statement	2013
168	Guideline: Environmental Protection Act 1994: Structures which are dams or levees constructed as part of environmentally relevant activities	Version 6
169	Guidelines for Ring Tank Storages, edited by Dr Hugh Barrett (Irrigation Australia Ltd)	Oct 2007 2nd Edition
170	**State Development and Public Works Organisation Act 1971**	19 June 2014
171	**Sustainable Planning Act 2009**	20 Feb 2014
172	Sustainable Planning Regulation 2009	4 Aug2014
173	Queensland Planning Provisions	25 Oct 2013, Version 3
174	State Planning Policy	Dec 2013
175	State Development Assessment Provisions (SDAP)	21 June 2013
176	Construction or modification of levees state code	9 May 2014 Version 1.3
177	State interest—natural hazards: Guidance on flood, bushfire and landslide hazards [draft version]	2 Dec 2013
178	State Planning Policy—state interest guideline: Natural hazards, risk and resilience	Aug 2014
179	State Planning Policy 1/03 Guideline: mitigating the adverse impacts of flood, bushfire and landslide	June 2003
180	Technical Manual - Evaluation report: Flood hazards	Aug 2014
181	Technical Manual - A ‘fit for purpose’ approach in undertaking natural hazard studies and risk assessments	Aug 2014
182	Technical Manual - Guidance for considering natural hazards, risk and resilience when designating land for community infrastructure	Aug 2014
183	Code for self-assessable development for taking overland flow water for stock and domestic purposes	2014 Version 9.1
184	Code for self-assessable development for taking overland flow water using limited capacity works	2014 Version 7.1
185	Code for self-assessable development for taking overland flow water to satisfy the requirements of an environmental authority or a development permit for carrying out an environmentally relevant activity	2014 Version 3.1
186	Building Regulation 2006	1 Feb 2012
187	Certification guidelines for assessable works that take overland flow water	2008
188	Code for assessable development for operational works for taking overland flow water	2012 Version 5
 189 190 191	*IDAS Forms:* IDAS 12 - Taking or interfering with artesian or sub-artesian water IDAS 13 – watercourse pump IDAS 14 – water storage	1 July 2013 Version 3.0

192 193 194	IDAS 15 – gravity diversion from a watercourse IDAS 17- water diversion IDAS 21 – other work in a watercourse	
195	IDAS Form 20: Interfering with overland flow water and construction and modification of a levee	16 May 2014 Version 4
196	IDAS Form 19: Taking overland flow water	1 July 2013 Version 3.0
197	IDAS Form 27 – waterway barrier works	1 July 2013 Version 3.0
198	IDAS Form 33 – Great Barrier Reef Wetland Protection	1 July 2013 Version 3.0
199	Application for licence to take water	2013 W2G001-v3
200	Application for licence to interfere with the course of flow	2013 W2G006-v6
201	Queensland Urban Drainage Manual	2013 Version 3
202	**Vegetation Management Act 1999**	31 Mar 2014
203	Local Government Grants and Subsidies Program (LGGSP) 2013-14 Local Government Floods Response Subsidy	June 2013
204	Joint Application Package 2014-15 Information pack for Queensland disaster mitigation and resilience funding available through the: Royalties for the Regions Local Government Floods Response Subsidy Natural Disaster Resilience Program	March 2014
205	Planning for stronger, more resilient floodplains (Queensland Reconstruction Authority) Part 1 & Part 2	Part 1: 2012 Part 2: 23 Jan 2012

Table 6.8: Commonwealth.

#	Document	Version
206	Managing the floodplain: a guide to best practice in flood risk management in Australia	2013 (2nd edition)
207	National Emergency Risk Assessment Guidelines	Oct 2010
208	Guidelines to good practice for the Construction and Refurbishment of Earthen Channel Banks (Land and Water Resources Research & Development Corporation)	Aug 2001
209	**Environment Protection Biodiversity Conservation Act 1999**	1 July 2014

Publication 7 preamble

Wenger, C. [under review]. The oak or the reed: how resilience theories are translated into disaster policies. *Ecology and Society*, submission number ES-2016-8425.

Disaster resilience has been a theme running through all thesis publications and analysis of the usefulness of this concept forms the final thesis research question.

In **publication 1** it was observed that 'self-reliance', promoted by resilience policies, was a logical adaptation strategy for climate change as recent flood reviews had illustrated that emergency response was likely to be overwhelmed in large disasters. **Publications 2 and 3** pointed to a possible flip side, that higher levels of government may not take adequate responsibility themselves, leading to *ad hoc* safety standards that might not reflect the level of risk. There is also the possibility that governments will allow development of floodable land and then put the responsibility for those decisions onto people who live there, people who may have little choice about where they live for housing affordability reasons. **Publication 3** demonstrated that 'disaster resilience' was at the heart of contemporary disaster policies in Australia and presented the mechanisms and programs through which it is funded. **Publications 4, 5 and 6** suggested that these programs fund preparedness activities but tend not to support activities such as house raising or relocation. However, resilience is also associated with initiatives that seem more positive. After the floods the Australian Federal Government provided a (once-off) betterment fund for Queensland to improve the resilience of public infrastructure such as roads and bridges. Betterment equates to the resilience idea of 'bounce forward' or 'bounce back better'. **Publication 6** demonstrates that improved flood information (a central theme of resilience strategies) does not prevent irresponsible development decisions being made and that even when substantial effort is invested in preparedness, this does not always lead to good behaviour response, such as participation in evacuation. **Publication 5** suggested that resilience policies were suited to Australia's non-interventionist style of governance as resilience is non-specific and allows state governments to select any measure and market it as 'improving resilience'. This will not necessarily lead to outcomes that are adaptive over the longer term.

These earlier publications therefore uncover both good and bad aspects of Australian disaster resilience policies and programs. But they do not conclusively answer whether 'resilience' is a useful concept when applied to emergency management (or whether it should be replaced and in which case, by what). Are the outcomes of resilience policies likely to be adaptive? Do they support transformation? Disaster resilience is also an international concept: do disaster resilience interpretations vary in different parts of the world? These are the questions I wanted to examine in **publication 7**.

My work on resilience began with the analysis of over 300 Australian media releases that used the word resilience in the context of flooding. This work was aborted for various reasons. However, it resulted in a prototype emergency management framework (revised from the standard PPRR framework) that I used in the methodology when collecting data for **publication 7**. I attempted to address deficiencies observed in the current framework (e.g., the absence of an 'anticipation' category) and I also attempted to make it easier to distinguish adaptive and maladaptive measures. While collecting data for **publication 7**, I continued to refine the framework when categorising different types of measures which my sources linked to increased resilience.

The preliminary media release study was also valuable for convincing me of the need for a systematic approach to complement my qualitative case study approach. This would help to limit the influence of my preconceptions and reveal things I might otherwise have overlooked. My earlier reading of program documents had alerted me to the fact that both levees and preparedness were linked to resilience, but what I discovered from using a systematic approach was that, especially in Queensland, roads were also linked to resilience, perhaps more strongly than any other type of infrastructure. Relatively few communities will end up with a levee but an improved road can be provided to any flood-affected community. Moreover, roads help people evacuate and provide access for emergency services, which correlates with a resilience focus on 'preparedness'. The media release exercise gave a different perspective on government disaster resilience policies and the way they were communicated and marketed to the public. It also highlighted the issue of incrementalism; it is not only levees that need to be built a bit higher and a bit stronger after each failure to cope with a flood.

Publication 7 also offered me the opportunity to complete my investigation into levees. Although I had examined levees in great detail, I felt this part of my work was unfinished. In **publication 5**, I researched ways to mitigate adverse levee impacts. At the end of **publication 6**, I proposed that levees could be viewed as a temporary solution but that more long term adjustments needed to be planned. However, I had not investigated *how* this could be done. Social-ecological system inspired resilience theory concerns the relationship between system elements and the feedback loops that reinforce these relationships. Several authors have suggested that a key area for resilience research is to identify intervention points to move from a bad resilience régime (or maladaptive system) to a more desirable one. The levee-development feedback loop seemed a good example that could be used in **publication 7**.

The oak or the reed: how resilience theories are translated into disaster management policies

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Abstract

While many researchers explore disaster resilience as an ongoing process or as a measurable property with indicators, few study whether disaster resilience policies are likely to lead to outcomes that are adaptive over the longer term. Some measures intended to increase local resilience may actually decrease the ability to cope with large-scale disasters. In the context of flood management, this work looks at activities supported in the name of resilience and whether these will result in long-term adaptive outcomes. It is proposed that traditional disaster management activities became linked to resilience when the concept transferred to the operational sphere of emergency management. At that point its interpretation became heavily influenced by pre-existing disaster management frameworks and concepts. These were not adequately re-assessed in the light of resilience theories.

With a focus on flooding, national disaster resilience policy documents from four countries and the global arena were examined to find out which activities are linked to resilience and whether this varies between countries. Sub-national policies were also examined in areas that had recently experienced major flooding. Resilience interpretations in some countries were found to support resistance strategies while others were more accommodating. The continued development of floodplains, facilitated by structural mitigation, is an example of a highly resilient but maladaptive feedback loop. This results in risk accumulation and higher consequences during extreme floods. Research explores in which way interventions could alter feedbacks to transform to more desirable resilience régimes. It is proposed that negotiating long-term adaptation pathways should be the ultimate aim for planners and emergency managers rather than resilience, which tends to support the status quo. Emergency management concepts and frameworks, such as Comprehensive Emergency Management, through which policies are implemented, need to be amended in the light of resilience theories to make it easier to achieve adaptive outcomes.

Keywords: Climate change adaptation; Disasters; Ecosystem-based approaches; Flood management; Levees; Resilience

1 Introduction

1.1 Disaster resilience: theoretical interpretations

In perhaps one of the oldest tales of disaster resilience, Aesop told a story about the oak and the reed. The proud oak stands strong and unbending against storms and mocks the reed, pushed about by every breeze. One day a storm of unprecedented magnitude whips up. Overcome, the inflexible oak is uprooted and dies. However, the reed humbly bows and once the storm passes, springs back up. This tale illustrates the folly of rigid resistance and the wisdom of acknowledging and accommodating powerful forces. It is also a tale that lends itself to the modern era of climate change, in which 'unprecedented' weather events are increasingly likely.

Resilience theorists today continue to debate the opposing elements of resistance and stability versus pliability, change and adaptability and the property of 'bounce back' displayed by the reed. As an engineering term, resilience is defined by the speed with which the object returns to a stable state or equilibrium (Bodin and Wiman 2004) and it incorporates 'robustness': the ability to both resist stress (rigidity) and absorb it (ductility) (Alexander 2013). The engineering characterisation of resilience has been used by some disaster management theorists, including Mileti (1999) and Norris *et al*. (2008). Operational disaster resilience definitions often reflect engineering resilience, when they use words such as 'resist', 'withstand' and 'rapid recovery' (see Supplement 1).

However, some disaster researchers have drawn attention to a fundamental opposition between the concepts of resistance and resilience, particularly when applied to social-ecological systems (de Bruijn 2004*a*; Liao 2012; Reghezza-Zitt *et al*. 2012). The battle of semantics had its origin in Holling's seminal work that applied the concept of resilience to ecological systems (Holling 1973). He felt that resilience was best described by the *persistence of a system* and the relationships between state variables, and not by its *stability* (which paradoxically, could lead to extinction). The most resilient systems, he argued, are often highly *un*stable, characterised by major fluctuations of system elements. This interpretation is felt to better reflect the complex and unpredictable interactions and feedbacks between ecological and social systems (Walker and Salt 2006). Holling's arguments are sound. However, the similarity between his definition of *stability* (which he distinguishes from resilience) and engineering-inspired dictionary definitions of *resilience* is striking, perhaps contributing to the enduring confusion of this term:

> [stability] represents the ability of a system to return·to an equilibrium state after a temporary disturbance; the more rapidly it returns and the less it fluctuates, the more stable it would be
>
> (Holling 1973: 14)
>
> [resilient] (1) Springing back; rebounding. (2) returning to the original form or position after being bent, compressed, or stretched. (3) readily recovering
>
> (The Macquarie Dictionary 1987)

Holling's focus is on the long-term survival of an ecological *system* despite (or because of) the fluctuations of component populations and conditions over time. However, this ecological perspective is problematic when transferred to social-ecological systems in general and disaster management in particular, as the fluctuation of human populations (or of elements on which humans depend) is not a tolerable view of resilience from a human perspective. Enabling the human component of the system to prosper is paramount. In a social-ecological system, this means maintaining human stability (population numbers, health, infrastructure, resource base, networks and social institutions) in the face of variable conditions. Human stability can be achieved either through artificially maintaining a stable state (using resistance strategies), or through the ability to operate under fluctuating conditions (using resilience strategies). The latter requires human flexibility and adaptation, and sometimes the manipulation of system feedbacks.

A resistant, stable system prevents change from occurring up until the point where resistance is overcome. However, stability erodes resilience in two ways. Firstly, it allows risks to accumulate. This means that when a large magnitude event occurs (overcoming resistance) it has greater impact, increasing the chance of a shift to an undesirable régime. Gunderson (2010) offers the ecological example of fuel build up in a forest where fires are suppressed. Applied to flooding, an artificially stable, dry system could enable inappropriate development to build up in a hazardous area.

Secondly, by preventing exposure to disruption, stability results in a system that can only operate in the 'stable state'. Stable conditions enable greater efficiency (less redundancy) and lead to an increasingly narrow operating space. Such communities forfeit the ability to function outside of this state which increases their vulnerability to large-scale events. Lack of exposure prevents learning from lesser events which also inhibits adaptation. In Liao's (2012) example, a levee creates a stable system that can only operate in dry conditions. Exposure prevention lowers risk awareness and response capacity. It also inhibits the use of construction standards that are flexible enough to cope with floods. Leveed areas, for example, may be excised from 'official' floodplains resulting in the absence or regression of flood-related construction or insurance requirements (ILPRC 2006; Keogh *et al*. 2011; State Government of Victoria 2014*b*; State Government of Victoria 2015).

Some observe the crucial role of exposure to lesser events in enabling communities to develop resilience, become self-reliant and to undertake adaptive action (Baan and Klijn 2004; Liao 2012; Zebrowski 2013; Engel *et al.* 2014). A related observation is that resilience is unlikely to develop in the absence of vulnerability (exposure being a component of vulnerability) (Gallopin 2006, Reghezza-Zitt *et al*. 2012). However, in the disaster risk management sector, hazard exposure is most commonly viewed as a negative element that increases risk (e.g., QRA 2012*b*; AGD 2013; USACE 2013).

1.2 Resilience and adaptability

Resilience of social ecological systems (SES) is often viewed in terms of adaptive capacity (e.g., Barnett 2001; Folke 2006; Norris *et al*. 2008). Indeed, the similarity between the two has led some to suggest that resilience is a redundant concept (Park 2011). This is reinforced by ideas such as 'bounce forward' (Manyena *et al*. 2011) and 'evolultionary resilience' (Davoudi 2012) that frame resilience as a process of continual improvement. In disaster management literature this is commonly described as 'betterment' or 'build back better'.

However, adaptive capacity is an imprecise term. Adaptation comes in many different forms and it is not always clear which is meant. Adaptation may be reactive, addressing obvious deficiencies through incremental adjustments, or it can question underlying values and structures, acknowledge the inevitability of large-scale change and aim for managed transformation. Either may be valid, depending on the potential magnitude of the problem and trade-offs involved.

In practice, betterment is often limited to upgrade. While this may be more sensible than reinstatement to prior standards, it remains an incremental measure, intended to maintain continuity during and following disasters. A ministerial funding announcement illustrates this point:

> Adelaide Street will be raised by 300mm and upgrades to storm water drainage will be made to improve flood resilience to a gauge level of 11.4 metres.
>
> (Crisafulli 2014*a*)

In this example, resilience is quantifiable and equates to water depth. It is a classic example of single loop learning (IPCC 2012) and there is no suggestion of a new way of thinking or approach that might ultimately prove more adaptive. Incremental change at the margins "is possibly the most dangerous path: a relief valve that gives the appearance of change and alleviates symptoms for a time" (Handmer and Dovers 1996:506). This may reinforce the status quo and path dependencies that lock future decisions into a maladaptive space (Barnett and O'Neill 2010, Wise *et al*. 2014). Using flood management as an example, adaptation may support the continued habitation and ongoing development of hazardous or ecologically-sensitive areas through the use of resistant measures such as levees. The same result could be achieved more subtly through land use planning and construction standards; whether such measures serve to maintain existing development patterns or to transform them ultimately depends on dominant, underlying philosophies.

Many resilience theorists pose the question: resilience of what to what (Carpenter *et al*. 2001), and this includes consideration of timescales. According to Holling (1996), ecological resilience is determined by the magnitude of the disturbance a system can cope with, which in flood management, is often described in terms of return period (average number of years between events). In the short or medium term a levee, a flood mitigation dam or a higher road can be expected to reduce economic damages and social impacts to small or moderate sized floods and is thus said to increase resilience. However, these same measures can reduce resilience over longer timeframes. For example, levees are associated with long-term geomorphological changes such as sediment starvation that can increase physical vulnerability (Yin and Li 2001; Smits 2006; Hudson 2008). Lack of exposure to frequent floods can decrease capacity to deal with infrequent, large floods (Larson 2009). A long-term perspective, aiming to maintain ecosystem performance and social capacity, can be equated to sustainability.

An unsustainable measure is likely to be maladaptive. Maladaptation is defined by Barnett and O'Neill (2010) as: 'action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability or other systems, sectors or social groups'. They identify five characteristics of maladaptation, of which path dependency, concerning long-term trajectories, is a key concern of this paper.

Where adaptive capacity is used in disaster resilience definitions, it is often a matter of interpretation as to which type of adaptation is meant. Adaptation that supports a resilient status quo does not lead to long-term resilience if it merely delays change and accumulates risks for the future. Resilience needs to support adaptation options that look to broader scales in space and time, across sectors and social groups (Adger *et al*. 2005). If resilience is determined by adaptive capacity, this should explicitly include transformational capacity, the ability to move to a more desirable resilience régime. Otherwise there is a risk that politicians, practitioners and the public may interpret 'ability to adapt' as narrow, reactive incrementalism. This is in line with other authors who have highlighted a need for SES resilience to incorporate transformative approaches to deliberately move to a new development trajectory, including Folke (2010), Chelleri and Olazabal (2012), Elmqvist (2014), and Matyas and Pelling (2015).

1.3 Transfer to emergency

The concept of resilience has transferred across many disciplines, including engineering, psychological health, ecological systems, and most recently, disaster management (Alexander 2013). The idea of resilience has been used in emergency literature since the 1970s but its meaningful interpretation in the context of disasters began almost a decade later (Torry 1979; Wildavsky 1988; Handmer and Dovers 1996). Disaster resilience finally emerged on the political stage following the 11 September 2001 terrorist attacks in the United States, with the formation of Britain's London Resilience Partnership and UK Resilience (LRRF 2006, Alexander 2013). Resilience has also been adopted into USA disaster management and has received international prominence through the United Nations International Strategy for Disaster Reduction and the Hyogo and Sendai Frameworks (UNISDR 2005; MCEER 2006; NRC 2012*b*). In Australia, a 2002 disaster mitigation review offers the first influential use of the word resilience (DOTARS 2004). Later it appears in Australia's inaugural National Security Statement (Rudd, 2008), and rapidly thereafter dominates emergency management funding programs and strategies (MCPEM-EM 2008; AGD 2009; COAG 2009; COAG 2011).

When adopted into operational disaster management, resilience was superimposed upon pre-existing concepts and operational frameworks. While the differences between resilience and the concept of vulnerability have been well-explored, there has been less examination of the relationship between resilience and the Prevent-Prepare-Respond-Recover framework (PPRR), also known as Comprehensive Emergency Management.

The PPRR framework was first developed in the USA in 1978 in an attempt to address the fragmentation of emergency management. There, a strong separation was observed between fast-action, operational 'preparation-response' phases and the evaluative, policymaking style of management required for mitigation and long-term recovery. Planning, funding and legislation for 'mitigation-recovery' were ad hoc, while the agencies and programs implementing them were uncoordinated and incomplete:

> …mere preparedness and response mechanisms are not enough. These must be coordinated with active mitigation and long-term recovery programs which should be set in the context of state development plans
>
> (NGA 1979: 9)

The PPRR framework rapidly transferred to Australia, with 'prevention' being substituted (or added to) the USA's 'mitigation' (Crondstedt 2002). With minor variations, it currently forms a basic structure for emergency management worldwide. However, while PPRR was originally intended to focus attention on mitigation and the integration of disaster phases (e.g. through preventative reconstruction in the recovery phase), in Australia these intentions failed to transfer and have yet to be achieved (DOTARS 2004; DAE 2013; Productivity Commission 2014*b*). This reflects a common issue whereby institutional bias results in disproportionately greater funding allocated to reactive response activities despite widespread recognition that investment in mitigation is more cost-effective (BTRE 2002; Garnaut 2008; Pitt 2008; Healy and Malhotra 2009; NCLS 2009; DAE 2013; UNISDR 2015*a*).

In recent times, PPRR has been criticised for not technically including the gathering of flood information and risk assessment, these being pre-requisites of prevention, and central to modern flood management (Crondstedt 2002; NFRAG 2008; Rogers 2011). Rogers (2011) suggests this can be addressed by simply extending the existing framework rather than abandoning it. This has been done in the UK, where anticipation and assessment have been added to the standard framework (HM Government 2013).

While the PPRR framework continues to be widely used, more recent emergency management policies and mechanisms have centred on the concept of improving disaster resilience. At first, resilience appears to be a paradigm shift away from the PPRR framework. Among the changes associated with resilience is a move from simply considering disaster *likelihood*, to consideration of *consequences* as well, corresponding with the modern risk-based approach (NRC 2012*a*). Related to this is the acknowledgement that no matter how much effort is invested into prevention, residual risk will remain and contingency measures are needed to reduce damages (NRC 2012*a*; AGD 2013). Another distinctive element of resilience is the twin concept of 'shared responsibility', which expects those who live in hazardous areas to become increasingly self-reliant (COAG 2011; UNISDR 2015*c*). People are thus transformed from being victims (vulnerable: negative) to actors in control of their own destiny (resilient: positive). This framing of ‘resilience’ is politically powerful; not only does it reduce government responsibility but the message of self-empowerment appeals to people’s desire to be strong enough to cope with setback.

Despite these conceptual shifts, resilience and PPRR are very closely intertwined. Both appear to have their origins in a desire to increase emphasis on preventative measures (UNISDR 2015*a*). PPRR also frequently appears in disaster resilience definitions or text. For example, Australia’s National Partnership Agreement on Natural Disaster Resilience defines resilience as “the capacity to prevent/mitigate, prepare for, respond to and recover from the impacts of disasters” (COAG 2009). Senior Australian bureaucrats, when discussing the establishment of new arrangements, state: “the foundations of this new way of thinking came largely from work within the field of organisational resilience…the aim of current EM policy is to use [the PPRR] model to work towards a more disaster resilient Australia” (Prosser and Peters 2010). Australia is not the only country where resilience and PPRR are closely connected. This also appears to be the case in the USA (e.g., DHS 2011; NRC 2012*b*; White House 2013*a*; DHS 2013) and internationally (e.g., UNISDR 2015*c*:S.17; United Nations 2005:Res.1.3). In the USA, executive orders and presidential policy directives often reflect PPRR in disaster resilience definitions, with 'anticipation' added and mitigate/prevent becoming adapt. In the Netherlands, PPRR takes the form of 'multi-level safety', which is said to enhance resilience (Zevenbergen *et al*. 2013).

The apparent seamless graft of resilience onto PPRR leads to the potential error that every measure within the PPRR framework (subject to local conditions) can be said to increase resilience. This is sometimes articulated even in academic circles (NRC 2012*b*; Cutter *et al*. 2014). However, as discussed above, theoreticians in the field of disaster resilience commonly distinguish between 'resilience' and 'resistance'. In this light, reassessment of the PPRR framework and the activities it supports is overdue.

2 Methods

This paper explores how resilience is applied operationally and the policy outcomes it supports. It aims to assess (1) how useful the concept of resilience is for emergency management; (2) whether it should guide emergency management policy or be replaced; and (3) if it needs replacing, what should replace it. A particular concern in this regard is the continuing development of floodplains, which puts more people at risk of flooding and damages the ecosystems and water quality on which societies depend (Tockner 2008). This fuels future demand for structural mitigation, which in turn supports additional development (Smith 1998), in a feedback loop that could be described as an undesirable resilience basin of attraction. Hence one of the issues examined was whether resilience policies support this maladaptive feedback loop or whether they support transformation out of it.

A literature review covering global sources and four national sources (China, The Netherlands, Australia and the United States) was used to investigate interpretations of 'disaster resilience' in the context of flooding. While flooding was the focus, sources sometimes covered more than one hazard type and many measures are applicable across hazards. Informed by a review of theoretical concepts, case study analysis took particular note of themes relating to resistance, exposure and transformation. The object was to determine the kinds of on-the-ground measures supported by the concept of resilience, and to identify commonalities and differences. A related goal was to explore the language used in resilience definitions and its influence on the type of measures supported.

Analysis required documents to link disaster resilience to an idea or an activity. For example, a sentence might state that a measure increases resilience, or it could be discussed under a 'resilience' title or subheading. Less direct links were also accepted. For example, one section of a document might link ‘flood mitigation’ or ‘disaster risk reduction’ measures to increased disaster resilience. Mitigation or risk reduction measures identified elsewhere in the document were therefore included, whether or not the section reiterated that their use increased resilience. Word search was used to help navigate documents and identify linkages.

It was not possible to cover all ‘disaster resilience’ documents produced by case study countries. Document selection therefore aimed to cover a range of document types, where possible including: nationally/internationally significant disaster resilience policy documents; climate change policies; documents generated by influential think tanks or agencies; strategic documents generated in jurisdictions that had recently experienced major floods; resilience program documents; and floodplain management guidance. For China and the Netherlands, research relied on English translations of publically available official documents (for additional information, see Supplement 3). Where government documents did not use the word ‘resilience’, academic sources written by a person originating from that country were identified using a scopus search (resili* + country).

For the purposes of this study, the standard PPRR framework was modified to incorporate an ‘anticipate’ category. It also restructures prevent/mitigate and prepare categories, resulting in a framework that is better able to distinguish resistance style measures and activities that are potentially more transformational. Measures such as land use change and development restrictions are in the avoid category, while structural resistance measures are largely covered by the 'exposure reduction' category. Preparedness has been classified under the broader 'accommodate' category, which comprises measures that help communities to live with flooding. Activities that sources linked to resilience were grouped under categories. The revised framework is provided in Supplement 2.

The literature review used a systematic approach whereby references were incorporated into the modified PPRR framework to determine the activities and ideas supported by the concept of disaster resilience (Table S.7.2). As there are limits to information that can be gleaned from a table, case study narratives were also prepared (Supplement 3).

2.1 Data analysis methods

For data analysis, the relative significance of each category within a country was assessed. This was expressed as the percentage of documents that associated the category with resilience (see results: Figures 7.1*a*-7.1*e*). This provides only a generalised overview as a document that only covers one activity within a category is weighted equally against sources that identified several activities. A potential bias observed was that many documents examine resilience in a specific context (such as critical infrastructure, dams and levees or land use planning), which makes it more likely for them to cover some categories than others. However, it could also be argued that if a single issue is of such importance to a country that it merits its own 'resilience' document, this is also significant.

To determine the relative importance of resistance measures that aim to maintain status quo, as opposed to transformational adaptation measures, more detailed analysis was carried out of three indicators: exposure reduction, ecosystems based approaches and underlying causes (the latter comprising three activities drawn from different categories). During the course of the research, it was observed that sources dedicated significant space and discussion to some measures, but inclusion of others appeared tokenistic. Therefore, a more granular analysis was undertaken of these 'indicator' categories and a weighting system was used. The rationale behind the weighting system was that the more significant the category, the more detail and depth should be provided by source documents and the higher the number of activities within the category were likely to be covered. Weighting was done by calculating the total number of activities for the relevant indicator and multiplying it by the total number of source documents in a country to arrive at a 100% saturation figure (number of possibilities). Then the *actual* number of sources for each activity in the country was calculated, to arrive at a saturation percentage. General trends were also checked without using the weighting system to verify they were consistent.

The exposure reduction category was used as an indicator for resistance (results: Figure 7.3). This excluded the 'improvement' activity, which proved ambiguous as some modifications aimed to increase resistance, while others aimed to permit more flooding. Ecosystem based approaches are strongly associated with a change in mindset and values, from control to acceptance of natural processes, and are thus illustrative of transformational adaptation (results: Figure 7.4). Another indicator of transformation is the willingness to analyse and address underlying causes, rather than responding to symptoms. For this, a meld of activities was selected from different categories (results: Figure 7.5).

2.2 Interpreting results

Several caveats should be made when interpreting results. Firstly, China's sample size was small as resilience was not a word used in English translations of official documents. It was therefore not possible to cover the same range of document types as for other case studies (Supplement 3). Secondly, while the Netherlands covers a good range of document types, early documents tend to be academic rather than government in origin. This said, sources examine government policy innovations and authors often have a close relationship with government agencies (e.g., have produced work for agencies; some authors identify themselves as government officials). It should also be noted that this study investigates the written word and not the relative financial support provided for different measures in program budgets. Were budgetary comparison to be made, it would be important to bear in mind that different measures vary greatly in cost, and that expenditure may not, therefore, represent a true picture of how resilience is interpreted.

3 Results

Data underlying results is provided as supplementary information. This includes a study of operational resilience definitions (Supplement 1), results data tabulated into the study framework (Supplement 2) and a resilience narrative for each case study (Supplement 3).

3.1 Statistical analysis: framework categories

A comparison of framework categories was undertaken for each case study area (Figures 7.1*a*-7.1*e*). National case studies show high variability between categories. The Netherlands has the largest variability, with 100% of sources linking resilience to *anticipate* measures, as compared with 14% interpreting resilience in terms of *respond*, a difference of 86 percentage points. The Global case study has the lowest variability. It broadly supports all categories with a difference of 33 percentage points between highest (*anticipate*) and lowest (*exposure reduction*). This may reflect the need to be inclusive on the international stage to accommodate the varying needs and approaches of all countries.

Figure 7.1*a*: China.

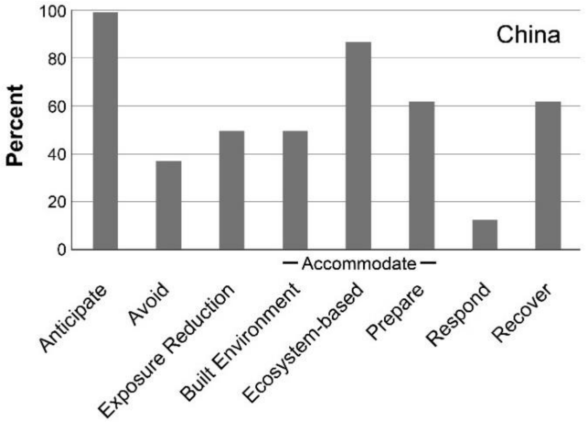


Figure 7.1*c*: Australia.

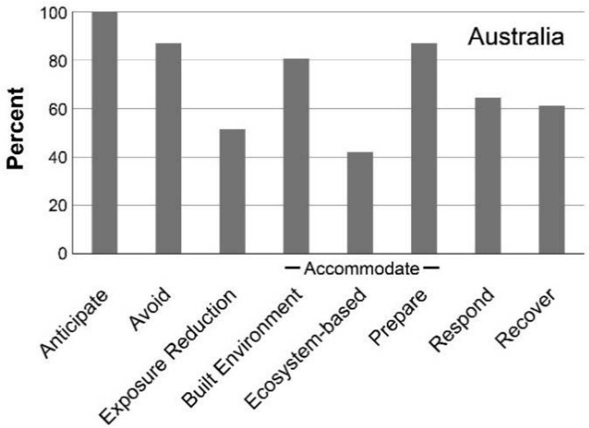


Figure 7.1*e*: Global.

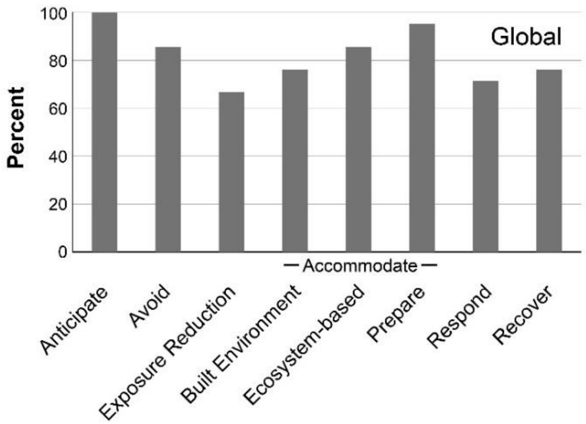


Figure 7.1*b*: The Netherlands.

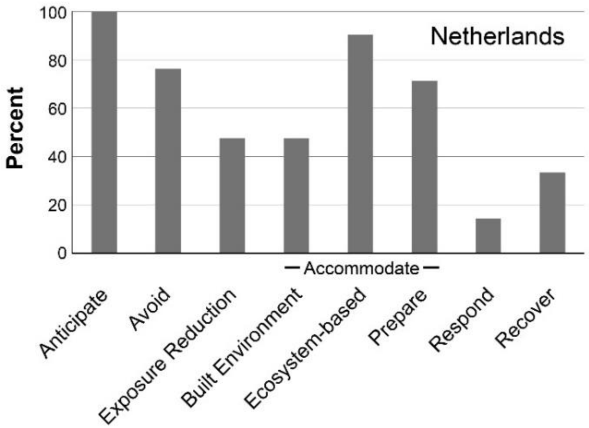
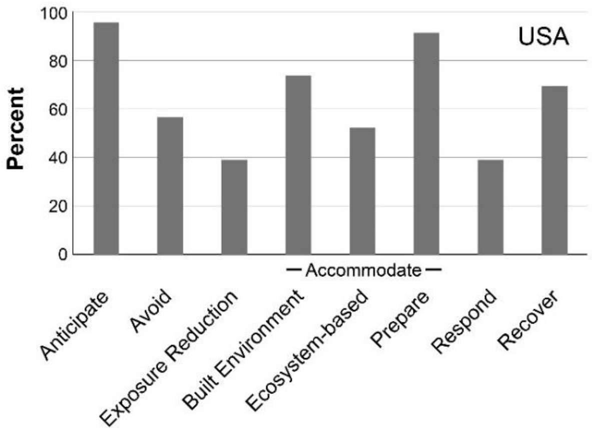


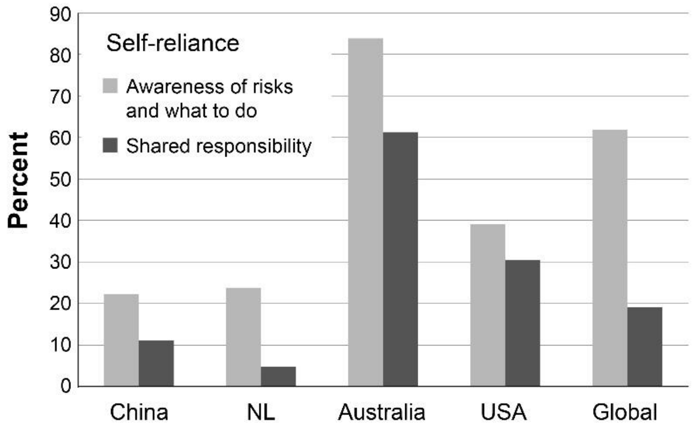
Figure 7.1*d*: USA.



Figures 7.1*a*-7.1*e* compare the relative significance of framework categories, expressed as a percentage of references linking at least one activity in the category to resilience.

Analysis indicates that all case studies strongly associate resilience with *anticipate* and *accommodate: prepare* measures. Of *accommodate: prepare* activities, Australia, the USA and Global all exhibit strong correlation of resilience with 'institutional arrangements', and Global displays by far the strongest link between resilience and 'reducing vulnerability of disadvantaged groups' (90%). Australia has the highest score for 'awareness of risks and knowledge of what to do before and during an emergency' (84%) and 'shared responsibility; self-reliance' (61%) (Figure 7.2). It also scores highly in related activities, 'capacity building' (65%) 'hazard information' (77%) and 'risk assessment' (94%), with recognition that information is a prerequisite for risk awareness and action. These findings reinforce a recent interview-based study of resilience framing by Australian flood practitioners, which found self-reliance to be a dominant theme (Aldunce *et al*. 2015). As suggested by the authors, this could be partly explained by neo-liberalism, a link well-explored by Zebrowski (2013). However, the current study suggests greater prominence of this interpretation in Australia compared with elsewhere. This could be a consequence of the Australian Federal Government's limited constitutional role in natural resources management. With restricted power over development planning (coupled with financial responsibility for large-scale disaster damage), the promotion of 'shared responsibility' is a logical policy choice.

Figure 7.2: Self-reliance.



The *avoid* category has strong correlation to resilience in all case study areas except China. On the surface, avoidance of flood hazard areas appears highly adaptive. However, sources are not necessarily explicit about the degree of avoidance intended. Policy documents from the Netherlands suggest a more forward-looking approach, whereby development is restricted in some areas to permit the expansion of floodable land should it be required in the long-term future (Deltacommissie 2008; NEAA 2011). However, in other instances land use planning and zoning requirements support business as usual. For example, development and economic growth agendas may 'balance' development, flood safety and environmental needs by limiting risk consideration to a 20 year timeframe within the (current) 1 in 100 AEP floodplain.

Effectively, this enables continued floodplain development (Wenger 2015*a*). Similarly, in the USA additional development is planned for sixty percent of land along the Atlantic coast within a metre of sea level (GAO 2015). Regardless of construction standards imposed in these zones, ultimately, controls may prove inadequate for addressing changing flood patterns associated with global warming.

Respond and *recover* receive somewhat variable support and are generally less significant than *anticipate*, *avoid* and *accommodate* categories. Australia and Global score highest in the *respond* category and the USA and Global are highest in *recover* (with 'financing recovery', particularly through insurance, being the most significant recovery activity for all case studies). These categories are least significant in the Netherlands, perhaps due to its high level of structural protection.

3.2 Resistance and transformation

Language in operational source documents often uses words such as 'withstand', 'resist' or 'protect'. This is found in both resilience definitions and text (see Supplement 1). Some definitions include both resistance and flexibility or adaptation, although only one definition was found that included capacity to transform (IPCC 2014).

A more detailed analysis was undertaken to compare the relative importance of resistance strategies (using *exposure reduction* as the indicator) and measures more strongly associated with transformational change (using *accommodate: ecosystem based approaches* (EBA) and a composite *underlying causes* category). The *underlying causes* category comprises 'investigate / understand underlying disaster causes' (*anticipate*) and two activities that address causes: 'climate change mitigation' (*avoid*) and 'reducing vulnerability of disadvantaged groups' (*accommodate: prepare*).

All case studies except Australia associate disaster resilience more strongly with *EBA* than *exposure reduction* (Figures 7.1*a*-7.1*b*). Comparison between countries (Figures 7.3, 7.4 and 7.5) reveals a similar picture. For *exposure reduction* measures (Figure 7.3), flood barriers, including levees, was the activity most commonly referenced. Note that Figure 7.3 excludes the exposure reduction 'improvement' activity, which proved ambiguous as some modifications aimed to increase resistance, while others aimed to permit more flooding. Global sources display the highest correlation of resilience with *exposure reduction*, (reflecting high support for all framework categories), Australia is second highest and the Netherlands the lowest. Conversely, the Netherlands and Global score the highest in the *EBA* category and Australia the lowest. This pattern could be attributed to the long history of levee use in the Netherlands, China and the USA, giving rise to greater evidence of levee problems in those countries than in

Australia (Wenger 2015*b*). This suggests a potential for bias within the *EBA* category, with Australia more likely to favour activities that preserve 'existing' landscape features (such as 'protect / enhance natural floodways and buffers: wetlands, riparian and coastal ecosystems'), and countries such as the Netherlands likely to favour 'rectification' activities (through measures such as dyke removal or relocation). To some degree this is the case. The former activity rates the highest mention among Australian sources, and the latter is highest in the Netherlands. However, even for the former, the Netherlands rates more highly than Australia.

Figure 7.3: Exposure reduction. *Exposure reduction is based on six activities and is used as an indicator of the relative significance of resistance measures in the interpretation of resilience between case studies. Scores are weighted (see methods).*

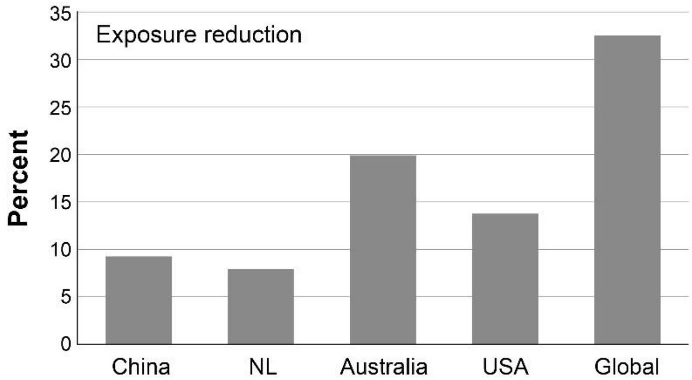
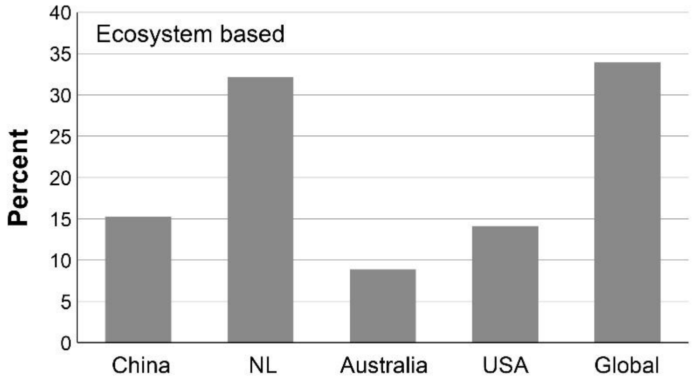
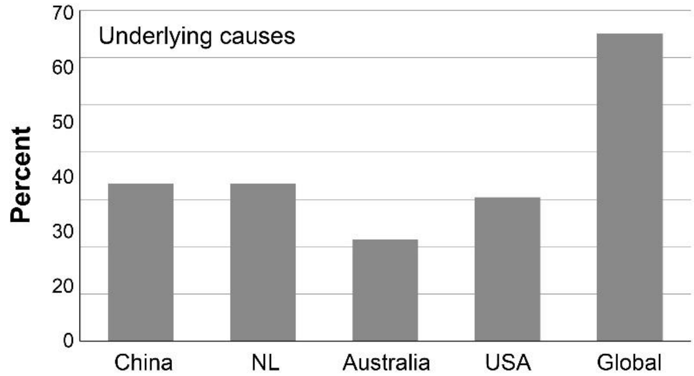


Figure 7.4: Ecosystem based approaches. *The prevalence of ecosystem based measures was used as an indicator of transformational interpretations of resilience. Scores are weighted (see methods).*



The other indicator used to reveal transformational interpretations of resilience was 'underlying causes' (Figure 7.5). Comparison between case studies shows Global is highest, China, the Netherlands and the USA are almost on a par and Australia is lowest. Although the global interpretation of resilience shows broad support for all categories, it is particularly marked for 'underlying causes'.

Figure 7.5: Underlying causes. *The relative importance of underlying causes has been calculated using three activities: understanding underlying causes; climate change mitigation; and reducing the vulnerability of disadvantaged groups. Scores are weighted (see methods).*



There are nuances in the way different case studies cover underlying issues that are not obvious in the broad-scale statistical analysis. When identifying underlying causes, national sources tend to focus most heavily on underlying climate issues and sometimes on natural resource degradation. Where social issues are covered it is usually in relation to population growth. By contrast, the global sphere (which also covers climate change and natural resource condition), is concerned with complex social equity issues. Some USA sources cover social disadvantage (CNY 2013; Thomas and DeWeese 2015), perhaps as a consequence of the 2005 New Orleans disaster where linkages between disadvantage and impacts were evident (Kates *et al*. 2006; Tierney 2006). The Netherlands rarely covers social inequity. The few that do either deny inequity (on the basis of health, access to information and income), or only mention it in the context of international policy. However, Wolsink (2006) makes it clear that power inequities in the Netherlands affect flood management outcomes. Australian sources often cover social inclusion to reduce vulnerability (for example, risk awareness campaigns targeting disadvantaged groups) but tend to avoid underlying issues that cause disadvantaged groups to be at greater risk.

Given that climate change is a commonly cited underlying cause, it is interesting that climate change *mitigation* is rarely associated with disaster resilience. This does not imply an absence of climate change mitigation policy, but is more likely to indicate policy division, with climate change portfolios addressing causes and disaster resilience addressing effects through adaptation options.

Overall, results suggest the Netherlands has the most consistently transformational interpretation of disaster resilience and Australia the most resistant, while in the global arena, relatively high support is shown for all measures.

4 Discussion

4.1 Changing feedbacks

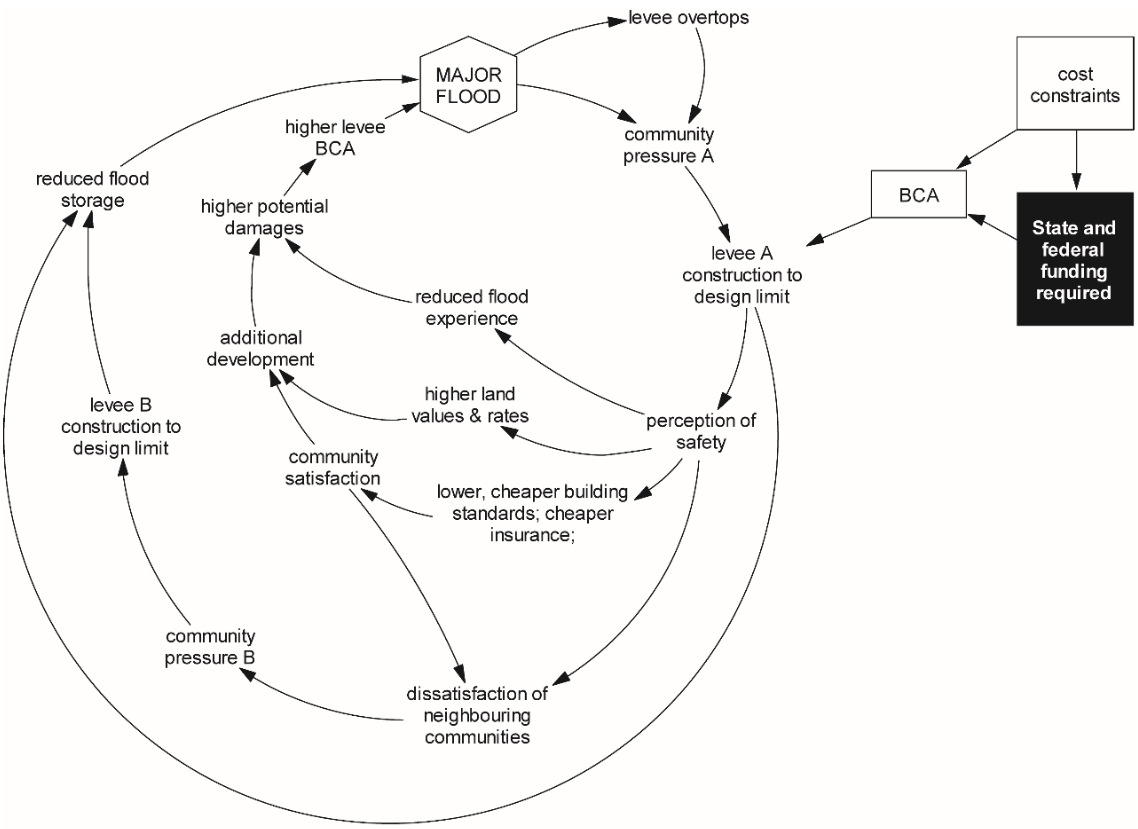
Reiterating the caveats to interpreting results outlined in the methods section (for example, the small sample of the China example), it is evident from results that the interpretation of disaster resilience varies according to country, some being more 'resistant' than others. However, to some extent resilience interpretations from all case studies support resistant measures such as flood barriers, and the use of language such as 'resist' and 'withstand' reinforces resistance as part of operational resilience ideology. While flexible words such as 'adapt' are often incorporated into resilience definitions, the degree of adaptation is limited so as to 'maintain existing systems and structures': the pursuit of stability and status quo. Moreover, 'adaptation' may be interpreted as encompassing any change, including the use of resistant measures.

It would appear, therefore, that ecological interpretations of resilience, which acknowledge the importance of exposure and instability, have largely been rejected at the political and operational level. As discussed above, when the concept of resilience was adopted it was superimposed onto the pre-existing disaster management PPRR framework. PPRR is not discriminatory and it incorporates a comprehensive suite of possible management options for each disaster phase. The more recent Disaster Risk Reduction (DRR) approach is also associated with resilience. It is similar to PPRR except that it focuses on action taken prior to disasters (PP, rather than RR), including an emphasis on underlying social causes. DRR definitions include exposure reduction (UNISDR 2009). This encompasses hazard avoidance through development planning. Equally it could mean measures such as flood barriers. The presence of pre-existing disaster management options and frameworks is likely to have coloured the interpretation of resilience when it transferred to the operational domain. Instead of reassessing possible management options in the light of academic theories about the true nature of resilience, it was easier operationally to create a meld of engineering and systems interpretations. In this way, all management options continued to be available. Resilience can thus justify *any* activity, which limits its usefulness as a guiding concept.

Of particular concern is resilience's stated aim in many definitions to 'maintain existing systems'. A social-ecological resilient system is one that retains essential feedbacks and identity (Walker *et al*. 2004), and resilience definitions that express the ideal of maintaining existing functions, systems and structures accurately reflect ecological and SES resilience theories. However, as many have pointed out, a resilient status quo is not necessarily desirable and may not lead to desirable adaptation pathways that will endure in the long-term (Wise *et al*. 2014). Resilience interpretations need to encompass the transition from less desirable to more desirable régimes, by identifying intervention points and deliberately altering system feedbacks. This has been identified as a priority for resilience research (Miller *et al*. 2010; Sjöstedt 2015).

The often-cited *levee paradox,* (Figure 7.6), also known as the *levee effect*, is a highly resilient undesirable system, whereby levees create artificially stable systems that encourage greater development of hazardous areas, and thus greater potential consequences (Smith 1998). As risk is a function of both likelihood *and* consequence, it is thus debatable whether levees can accurately be described a 'risk reduction' measure. Levees ameliorate short to medium term flood risk. However, they are unlikely to cope with 'unprecedented' floods or events of a magnitude outside living experience, such as the storm that felled the oak. Such events are likely to occur more frequently due to climate change and the IPCC remarks on the "unavoidability of sea level rise in the long term even with stringent mitigation" (IPCC 2014:366). Ultimately, relocating at-risk assets may be the only option.

Figure 7.6: The levee paradox. *This diagram, based on Smith's (1998) description, illustrates a system of incentives and feedbacks that encourage levee construction and risk accumulation. External funding is available, subject to benefit cost analysis (BCA) which limits the design protection level. Nevertheless, it generates a perception of safety that encourages continuing development. Meanwhile other communities, perhaps in the same rate-paying local government area, observe benefits flowing to the levee-protected community and pressure mounts for similar levee protection. Additional development (associated with increased runoff) and reduced flood storage effectively reduce the protection afforded by the initial levee design. The levee overtops in a major flood, and pressure mounts for incremental increases in levee height.*



The levee paradox is a feedback system that supports the development of floodplains and the proliferation of additional and higher levees into the future. It is supported by inadequate planning legislation and 'resistant' interpretations of resilience that treat the symptoms of bad planning with structures. Levee drawbacks are widely recognised and even sources that support them also draw attention to their ecological and safety problems. The paradox thus forms an interesting transformational challenge.

At this juncture, it is important to question what is meant by 'a resilient status quo': what is resilience trying to preserve? Some view this in geographic terms: people continuing to live and work in the same place, maintaining their location-based identity, including its sub-culture, history and economic base (e.g., Klein *et al*. 2003; Campanella 2006). The locational definition is a practical unit from an emergency management point of view (McAslan 2010). According to this perspective, a city lacking resilience is unlikely to be wiped out, but it could decline following disaster, or conversely strengthen if resilient (Gunderson 2010). Taking a more institutional viewpoint, resilience could be viewed in terms of the underlying power structures it supports, which may or may not be desirable. Inequity in existing social landscapes can result in disadvantaged groups being assigned to hazardous (but affordable) locations in low quality housing that will perpetuate long-term risks. Policies to increase resilience may focus on short-term actions and recovery in preference to addressing these underlying causes (Sudmeier-Rieux 2014), while focus on short term economic objectives may undermine long-term livelihoods (Chelleri and Olazabal 2012). Finally, recovery efforts may discriminate between social groups and industries in a way that further entrenches disadvantage and benefits existing power structures (Vale 2014). In the results section it was seen that countries differ in their attention to underlying issues. For long-term, sustainable solutions, disaster resilience strategies need to recognise and address root causes of risk and vulnerability. In the case of the levee paradox, the resilience aim might be the preservation of a development and economic growth paradigm, whereby as much land as possible is made available for development as cheaply as possible, including 'low value' swampland (Burby 2006). This is where institutional feedbacks favouring levees intersect with higher level government policies that promote economic growth, employment and affordable housing (Abel *et al*. 2011).

Such policies are challenged when social thresholds are breached and create discontent, such as air pollution in China, or environmental damage caused by structural mitigation in the Netherlands (Huitema 2002; P.R.C. 2015*a*; Rohde and Muller 2015). Change of mindset (e.g., from 'control floods' to 'live with floods') underlies feedback change, motivating political will and enabling public acceptance. For a change of mindset to occur, a society may have to experience *firsthand* the draw backs of large scale flood 'control'. Merely observing the experience of other countries may not be sufficient incentive to do things differently.

One of the biggest issues invoked in debates about different adaptation options is trade-offs (IPCC 2014; Chelleri *et al*. 2015). Often, options that are more desirable from a long-term or ecological viewpoint are less desirable from a social perspective. For example, while flood studies might show that an area is at considerable risk of eroding coastlines, storm surge and flooding, some occupants, including the elderly, may not be able to afford the costs of retrofitting, and the relocation of long-term residents might cause great grief. An asset may still have many years before it needs replacing or rebuilding elsewhere. A socially-responsible response might provide for both short-term safety and allow time and incentives for long-term transformational adaptation to take place.

Figure 7.7 looks at options to alter levee paradox feedbacks. In this example, levees are used as a temporary solution to enable adjustment to take place. Time-limited protection coupled with funding conditions create incentives to either remove susceptible development from the floodplain or replace it with development types and designs that can accommodate long-term changes in flood risk. Theoretically, this would alter feedbacks, reducing exposure and impacts and lowering the imperative for protection. While not identical (in that levee decommission was not planned), there are examples of levees being used to assist adjustment to higher flood risk by allowing time for it to occur (Western and Kellett 2014). There is also a precedent for time-limited approval, which has been used for other types of hydrological structure, including dams (Russo 2000; Pittock and Hartmann 2011).

Pre-planned decommission may be an unpopular concept. However, it would provide added incentive for change and would prevent long-term damage to hydrological systems. It would also reinforce the idea that hazard risks are no longer stationary due to climate change and that levees are not a long-term solution. Another common issue affecting levee safety is lack of maintenance by local governments, due to cost or complacency, and consequent unreliability as levees age. Levee decommission could be planned to occur before significant maintenance issues are anticipated.

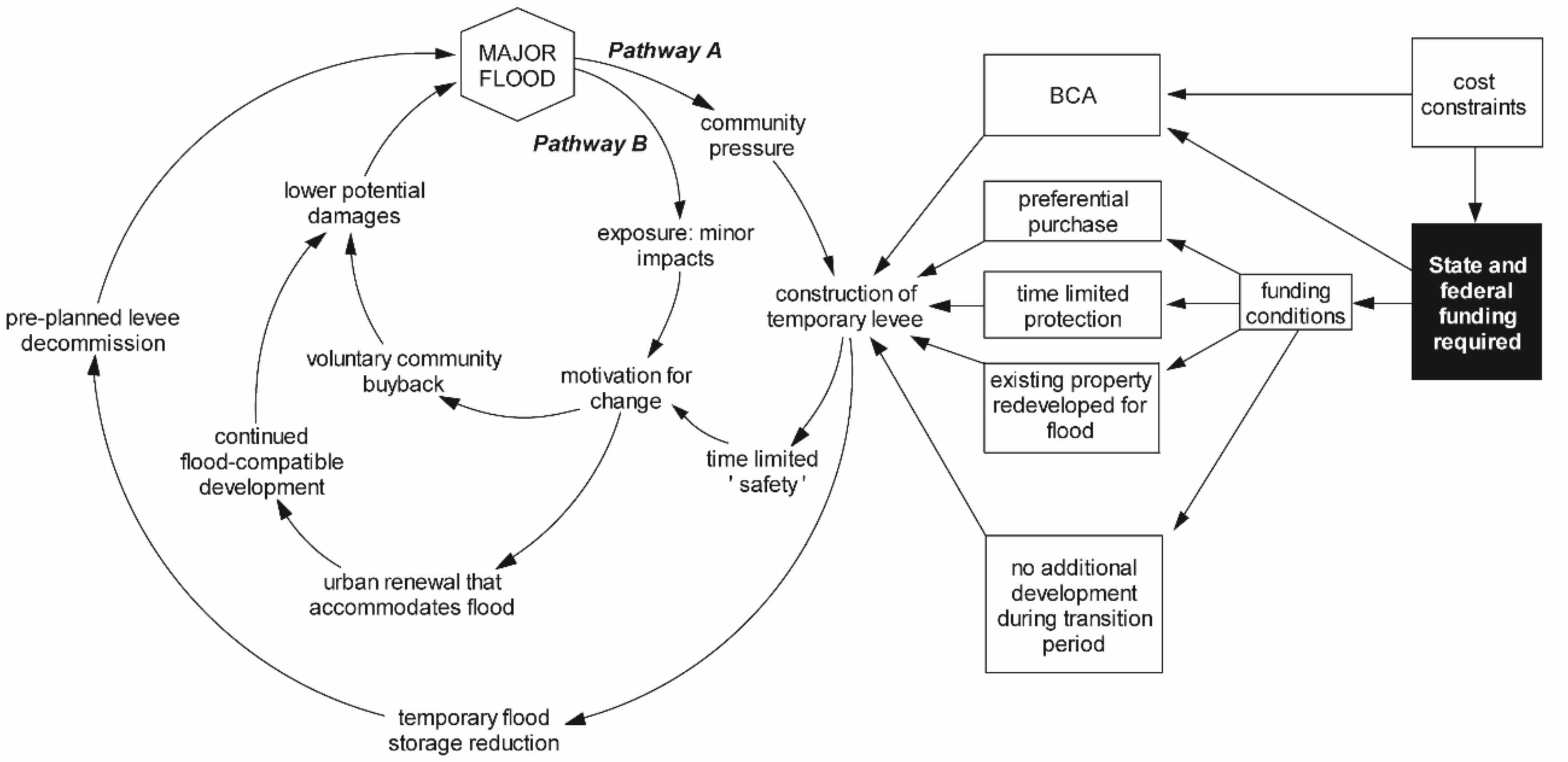


Figure 7.7: Changing feedbacks. *Altered system feedbacks may lead to transformational change and greater long-term resilience. External funding provides transitional protection (Pathway A), allowing communities both time and incentives to adjust voluntarily. Incentives such as inbuilt requirements for levee decommission remove the perception of permanent protection. Existing residents may remain. However, in return for temporary protection, governments may require that buildings be modified or apply preferential purchase agreements at (indexed) pre-levee prices to implement land use change over the longer term. While retrofitting or rebuilding existing structures is encouraged, a temporary moratorium on additional development prevents perverse incentives for development intensification within levee-protected areas. By the time the levee is decommissioned (Pathway B), the high-risk area has undergone changes that enable better accommodation of flooding and reduced impacts. Ongoing exposure engenders flood experience and motivates continual improvement.*

There are other potential intervention points in the levee paradox. Unless raised haphazardly with bulldozers as a flood approaches, levee building is an expensive exercise involving flood studies, options assessment, consultation, cost-benefit analysis, assessment of off-site impacts, design and construction. It is often beyond the financial means of local governments and usually requires funding from higher levels of government. In Gympie, Queensland, the more transformational option of removing development from the floodplain only gained support once the levee option, which would have attracted state government funding, was abandoned (Crisafulli 2014*b*). The very willingness of higher levels of government to fund large-scale engineering projects can prevent the implementation of sustainable, long-term solutions.

4.2 Shared responsibility and climate change adaptation

Case studies exhibit a strong link between disaster resilience and preparedness, including shared responsibility and self-reliance. This is a sound climate change strategy, as recent flood events illustrate that emergency services are easily overcome in extreme events (Pitt 2007; Comrie 2011; QFCI 2011).

However, shared responsibility equates to responsibility for residual risk and can mask underlying causes such as inadequate development policies. Once flood risk information is made available, the onus is on individuals to accept the risks they live with and to act accordingly. This is based on the premise that people have a choice, which for financial and employment reasons might not be the case (UNISDR 2015*a*). Shared responsibility on a community level usually involves local governments taking responsibility for risk management. However, higher levels of government may not devolve the power or provide the necessary legal backing for local governments to impose adequate planning controls. Higher level development interests may over-ride local safety concerns and participatory processes may only provide an illusion of choice. In Australia, for example, sea level benchmarks have been abandoned and state government legislation and policy fail to support local governments wishing to prevent unsafe development (Pang and Gordon 2004; QFCI 2012:191-192; SCCG 2012*b*; Sellers and Mooney 2012; Kellett *et al*. 2014; Stokes and Faulkner 2014).

4.3 If not resilience, then what?

While the conclusion of this paper is that resilience is too malleable a concept to guide disaster management, the convergence between resilience and adaptation theory offers great potential for the reassessment of operational frameworks. These research fields concur on the undesirability of structural options, such as levees. Adaptation theorists view them as maladaptive (Adger *et al*. 2005; Barnett and O'Neill 2010), while Holling's (1973) ecological interpretation of resilience suggests that such stability-inducing interventions prevent long-term resilience.

Holling's resilience theory could be usefully applied in helping to amend existing emergency management frameworks, so that they distinguish between resistant and accommodating management options. The amended framework developed for this paper offers a starting point but needs further refinement, the current work being constrained by the level of detail offered by source documents (Supplement 2). For example, the intent behind activities such as avoidance and construction standards could be made clearer (whether to enable continuing development in hazardous areas or to preserve floodable landscapes for the future). A more discriminating framework could help emergency managers and development planners to better negotiate pathways that are adaptive in the long term. Echoing the findings of Klein *et al*. (2003), it is suggested that negotiating adaptive pathways would be a better objective for disaster management than resilience.

5 Conclusion

Many theorists argue that resilience is best conceptualised as a measurable property and much effort goes into developing resilience indicators. Others prefer to see resilience as a process characterised by adaptive capacity, the process of modifying systems to ever-changing circumstances. As such, resilience cannot have an end-point. But few study whether disaster resilience policies are likely to lead to long-term adaptive outcomes. Once 'resilience' is operationalised, outcomes cannot be brushed aside. It is vital to determine the end result of disaster resilience strategies to assess whether they lead to desirable outcomes in terms of long-term climate change threats and the sustainability of natural resource systems upon which human societies depend. This requires examination of how resilience theories translate into policy and activities.

Resilience is useful politically. Its empowering message beguiles and motivates. Moreover, it is sufficiently ambiguous to support a wide variety of management policies: in Australia, it is used to support structural approaches and the continued development of floodplains, while in the Netherlands it is used to support floodable landscapes. This lack of consistency may be due to resilience theories having been superimposed upon the PPRR framework without much analysis, to the extent that they are sometimes expressed in almost identical terms. Assessment of the PPRR framework in the light of resilience theory suggests there is a commonly held view that 'all' mitigation or disaster risk reduction activities lead to increased resilience, despite many of these being resistance-style measures. Yet as described by Holling, resilience entails increasing the ability to cope with instability through acceptance, not elimination of exposure. The PPRR framework fails to distinguish between measures conducive to long-term resilience and maladaptive options that are less likely to achieve this.

In this paper, it is argued that disaster resilience policies need to be more discriminatory in the activities they support or they will not lead to adaptive outcomes able to cope with large-scale climate change events. Emergency management frameworks need to be critically assessed and revised and measures reviewed to determine how they can contribute to long-term desirable outcomes. While resilience theories have contributed to analysis and theoretical debate among researchers, *practitioners* would do better to focus on adaptation and the ultimate disaster management objective should the ability to negotiate a sustainable adaptation pathway. As in Aesop's tale, those who live at the water's edge cannot afford to be rigid but need to be able to *accommodate* the power and abundance of floodwater and transform it into advantage. Conversely, the pathways likely to lead to maladaptive outcomes, such as ongoing floodplain development and financing protective structures that enable this development should be discouraged. While easy to state, this requires strong political leadership. It may be that only the occurrence of a calamitous event is able to prompt such a deep and widespread questioning of existing policies and the values on which they rest.

6 Acknowledgements

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Supplement 1: Deciphering resilience definitions

In Table S.7.1, words and phrases are coded using colours which are explained in the section 'deciphering resilience definitions', below. This is intended to help rapidly determine which definitional element is in each resilience definition.

Table S.7.1: Resilience definitions found in policy and report documents.

Definition	Source
1. Global	
The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organising itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures. †	(UNISDR 2005)
The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.	(UNISDR 2009)
The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.	(IPCC 2012) (WB and GFDRR 2013)
The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.	(IPCC 2014)
The capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity and feedbacks.	(GEF 2015*b*)
The capacity that people or groups may possess to withstand or recover from emergencies and which can stand as a counterbalance to vulnerability	(Jha *et al*. 2012) [a World Bank publication]
2. USA	
The ability of social units (e.g., organizations, communities) to mitigate risk and contain the effects of disasters, and carry out recovery activities in ways that minimize social disruption while also minimizing the effects of future disasters.	(MCEER 2006)
Disaster Resilience may be characterized by *reduced failure probabilities* (i.e. the reduced likelihood of damage to and failure of critical infrastructure, systems, and components); *reduced consequences from failures* (in terms of injuries, lives lost, damage, and negative economic and social impacts); and *reduced time to recovery* (time required to restore a specific system or set of systems to normal or pre-disaster levels of functionality).	(NIST 2008)
The capability of an asset, system, or network to maintain its function or recover from a terrorist attack or any other incident.	(DHS 2006)

The ability to resist, absorb, recover from, or successfully adapt to adversity or a change in conditions.	(DHS 2009)
ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption ability of systems, infrastructures, government, business, communities, and individuals to resist, tolerate, absorb, recover from, prepare for, or adapt to an adverse occurrence that causes harm, destruction, or loss	(DHS 2010) (White House 2010)
the ability to withstand naturally variable conditions and/or recover from disturbances	(CPRA 2012)
The ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies.	(White House 2011) (DHS 2011) (HSRTF 2013:37) (FEMA 2015*b*) (FEMA *2015c*)
1. Able to bounce back after change or adversity. 2. Capable of preparing for, responding to, and recovering from difficult conditions. Syn.: TOUGH See also: New York City	(CNY 2013)
the ability to anticipate, prepare for, respond to, and adapt to changing conditions and to withstand and recover rapidly from disruptions with minimal damage	(USACE 2013)
The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.	(HSRTF 2013:169) (White House 2013*a*) (White House 2014)
The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.	(White House 2013*c*) (DHS 2013)
the ability to withstand and recover from both natural and man-made hazards [p.6] the capability of systems to prevent or protect against significant multihazard threats and the ability to recover rapidly and ensure continuity of critical services, with minimal negative impact to public health and safety [infrastructure resilience] [p.149]	(ASCE 2009)
capability to prevent or protect against significant multihazard threats and incidents and the ability to expeditiously recover and reconstitute critical services with minimum damage to public safety and health, the economy, and national security [infrastructure resilience]	(ASCE 2013)
A disaster-resilient nation is one in which its communities, through mitigation and pre-disaster preparation, develop the adaptive capacity to maintain important community functions and recover quickly when major disasters occur.	(NRC 2011)

ability of a system to absorb disturbance and quickly return to normal or a new normal while maintaining its identity and ability to function [p.*ix*] the ability of a system to absorb change and disturbance while maintaining its basic structure and function [p.4] the capacity of a system to absorb change and disturbances, and still retain its basic structure and function—its identity [p.28]	(NRC 2012*a*)
The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. ‡	(NRC 2012*b*)
The ability to prepare and plan for, absorb, recover from, and more successfully adapt to disasters [preface] The ability to prepare and plan for, absorb, recover from, and more successfully adapt to actual or potential adverse events….the ability of individuals, communities, localities, states, regions, and the nation to respond and recover in a manner that minimises disaster life and property losses and enables rapid return of normal economic and other life activities in the wake of disasters [p.7]	(GAO 2015)
• the ability to become strong, healthy, or successful again after something bad happens • the ability of something to return to its original shape after it has been pulled, stretched, pressed, bent, etc.	(Merriam-Webster Dictionary 2016)
3. UK	
Resilience measures aim to reduce the consequence of flooding by, for example, facilitating the early recovery of buildings, infrastructure or other vulnerable sites following a flooding event or by ensuring that key infrastructure such as power distribution centres, telecommunication control centres and key emergency access routes have enhanced levels of protection or other mitigation measures.	(DEFRA 2005)
Ability of the community, services, area or infrastructure to detect, prevent, and, if necessary to withstand, handle and recover from disruptive challenges	(Cabinet Office 2013)
Provide resilience for the UK by being prepared for all kinds of emergencies, able to recover from shocks and to maintain essential services.	(HM Government 2010)
The capacity of an individual, community or system to adapt in order to sustain an acceptable level of function, structure, and identity.	(Cabinet Office 2011)
The ability of a system or organisation to withstand and recover from adversity [p. 240] the ability of the community, services, area or infrastructure to withstand the consequences of an incident [p. 461]	(Pitt 2008)
I. Literal applications. 1. The action or an act of rebounding or springing back; rebound, recoil. *Obs.* 2a. Elasticity; the power of resuming an original shape or position after compression, bending, etc. 2b. *Mech.* The energy per unit volume absorbed by a material when it is subjected to strain; the value of this at the elastic limit. II. Figurative uses. 3. The action of going back upon one's word. Cf. resilement n. *Obs. rare*	(Oxford English Dictionary 2016)

4a. The action of revolting or recoiling *from* something; an instance of this. Now *rare*. 4b. Repugnance, antagonism. *Obs. rare*. 5. The quality or fact of being able to recover quickly or easily from, or resist being affected by, a misfortune, shock, illness, etc.; robustness; adaptability.	
1 The capacity to recover quickly from difficulties; toughness 2 The ability of a substance or object to spring back into shape; elasticity	(Oxford Dictionaries 2015)
4. Australia A measure of how quickly a system recovers from failures.	(EMA 1998)
The amount of change a system can undergo without changing state.	(COAG 2007)
The ability of a social or ecological system to absorb disturbances while retaining the same basic infrastructure and ways of functioning, the capacity for self organisation and the capacity to adapt to stress and change.	(DCC 2009)
The capacity to prevent/mitigate, prepare for, respond to and recover from the impacts of disasters.	(COAG 2009) (QRA 2011*b*:7)
The capability to prevent/mitigate, prepare for, respond to and recover from the impacts of disasters.	(COAG 2014)
[pseudo-definition] The capacity to prepare for, withstand, respond to and recover from disasters	(QRA 2011*b*: footer throughout)
[pseudo-definition] capacity to withstand and recover from emergencies and disasters	(COAG 2011) (QRA 2011*b*:10) (State of Queensland 2011) (AGD 2013)
[resilience characteristics] • functioning well while under stress • successful adaptation • self-reliance • social capacity	(COAG 2011)
The ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption.	(Queensland Government 2014*c*)
The ability of the Queensland Government, local governments, communities, businesses and individuals to prepare for, respond to, and manage potential hazards and disasters, thereby minimising impacts and rapidly recovering to emerge stronger and better able to cope with future disaster events.	(Queensland Government *2014b*)

The ability of communities to continue to function when exposed to hazards and to adapt to changes rather than returning to the original pre-disaster state.	(Productivity Commission 2014*b*)
Resilient: (1) Springing back; rebounding. (2) returning to the original form or position after being bent, compressed, or stretched. (3) readily recovering, as from sickness, depression , or the like; buoyancy; cheerfulness. ['Resilience' is defined in similar terms as 'resilient power' or 'resilient action']	(The Macquarie Dictionary 1987)
5. Netherlands [§]	
The speed of recovery from an unsatisfactory condition	(de Bruijn 2004*a*)[ǀ] [after ASCE and UNESCO 1998]
The ease with which a system recovers from floods [distinguished from resistance: 'the ability of such a system to prevent floods']	(de Bruijn 2004*b*)
The capacity of a dynamic system to absorb shocks while maintaining its structure and functioning (which is different from the capacity of a system to return to a certain steady equilibrium state following a disturbance). This definition focuses on 'persistence, adaptivity, variability, and unpredictability' and is 'measured by the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behaviour'	(van Slobbe *et al*. 2013)
Striving towards an appropriate balance between protection, prevention and preparedness, both now and into the future.	(Zevenbergen *et al*. 2013)
[UNISDR 2009 definition] The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.	(Weieriks and Vlaanderen 2015)
1. China	
N/A	

† Also adopted by the US National Science and Technology Council's Subcommittee on Disaster Reduction (SDR, 2005, p.17)

‡ A report commissioned by eight US government agencies including FEMA, USACE and the Department of Homeland Security.

§ Government documents from the Netherlands used in this study did not define resilience.

ǀ Currently a senior researcher at Deltares, specialising in flood risk management and resilience.

¶ Weieriks is from the Ministry of Infrastructure and the Environment (NL) and Vlaanderen is a member for Netherlands on the UN Secretary General's Advisory Board on Water and Sanitation.

1. Deciphering resilience definitions

Anticipate

There is some debate about the role of anticipation in achieving SES resilience. Some equate it to an attempt to achieve certainty in inherently unpredictable, complex systems (Handmer and Dovers 1996; Walker and Salt 2006; Gunderson 2010). Nevertheless it has strong ties to disaster resilience. It is a pre-requisite of disaster preparedness and risk reduction, and can motivate planned adaptation (IPCC 2012; Reghezza-Zitt *et al*. 2012; Matyas and Pelling 2015; UNISDR 2015*c*).

Anticipation includes a wide range of measures such as gathering hazard and vulnerability information and assessing it. On a shorter timescale, it also covers flood warnings. Anticipation is particularly relevant to contemporary disaster management due to projected climate change and uncertain future risks. This is well-reflected in this study's source documents, and anticipatory activities are perhaps more consistently linked to resilience than any other category of measures. It is therefore surprising that only three resilience definitions include 'anticipate'.

Anticipation usually involves evaluation (balancing options against each other and predicting their effects, costs and benefits). The dominance of technical experts in flood study and assessment processes and the use of decision-making tools such as benefit-cost analysis may create a bias towards technical resistance-style solutions (Molle *et al*. 2009; Wenger 2015*b*).

Mitigate, prevent

This covers a wide range of measures, including resistance, avoidance (through land use planning), construction standards, drainage, ecosystem-based measures, retrofitting and relocation.

Prepare

Preparedness measures acknowledge residual risk and cover risk awareness and contingency planning. These activities contribute to coping capacity during a disaster. Preparedness is occasionally used to encompass mitigation, i.e., a community that has invested in 'flood resilient' evacuation routes may consider itself to be better prepared.

Cope

Coping is short-term adaptation that enables survival and continued, if impaired, functioning during and following an event. Ability to cope is dependent on capacities (and vulnerabilities) already in place prior to the event. A paradox exists whereby 'disaster' implies inability to cope. Ability to cope thus implies 'no disaster'. The emphasis is therefore on increasing the coping range (Yohe and Tol 2002; IPCC 2012). In SES resilience theory, this relates to the size of the basin of attraction (Walker *et al*. 2004; Liao, 2012).

Increasing the ability to cope requires system adjustments to ensure the *stability* of the human element of a system (and of components on which humans depend), thus representing a departure from ecological resilience as described by Holling (1973).

Absorb and accommodate

These terms have a similar short-term timeframe as 'cope' but are more passive. They suggest innate structural and spatial qualities (e.g., through amphibious building standards or landscape features). In the case of flood hazards, they aptly describe ecosystem approaches which soak up, retard or store water (e.g., wetland protection, vegetation for water infiltration, unconstrained floodplains). Accommodate may also relate to social values and imply tolerance and preparedness to a degree of flooding or disruption.

Ability, capability and capacity

'Ability', 'capability' and 'capacity', are sometimes used interchangeably. In the emergency sector, the USA and the UK favour the use of 'capability' (DHS 2010; Cabinet Office 2013). Australian definitions tend to distinguish 'capability' (e.g., technology, management systems and skills) from 'capacity' (e.g., staff and volunteer numbers, amount of resources, redundancy, substitutability, and mobility):

> capability refers to the emergency management system's technical and other abilities to deliver a service. Capacity refers to the extent to which the system is able to sustain application of this capability for long periods or across multiple locations.
>
> (State of Victoria 2012*a*: 32)

The USA and the UK only define the term capability:

> A demonstrable ability to respond to and recover from a particular threat or hazard
>
> (Cabinet Office 2013:6)
>
> to accomplish a mission, function or objective
>
> (DHS 2010: 9)

When not used in a technical context, capacity may be applied to built form, for example, 'capacity to withstand' but it is also suggestive of social enabling and capacity building, a key element of resilience and its twin concept 'shared responsibility'. This aims for individuals and local communities to develop their own capacities for coping with disaster.

Withstand, resist, protect

These terms are most strongly associated with resistance strategies and generally apply to the built form, including structural protection to *prevent* exposure (e.g., flood barriers) or the ability of buildings or structures to *survive* exposure up to a specified magnitude (e.g., water or wind velocity, flammability, earthquake shock). Thus they could apply to either 'exposure prevention' or 'accommodate: built environment' strategies.

Respond

Response refers to emergency capacity and capability during an event. As such, it is also related to 'cope', 'absorb and accommodate' and 'withstand and resist'. However these are properties that need to be developed prior to an event taking place.

Maintain essential structures and functions

[or preserve; retain]. This is a dominant concept in SES resilience theory and relates to system change (Walker *et al.* 2004). Applied to disaster management, the phrase sometimes refers to functional continuity during a disaster (which is akin to the ability to 'resist', 'absorb' or 'accommodate'). Other definitions refer to the degree of system change following a disaster. These often display a definitional tension between adaptability /change and the need to stay the same. This suggests desire for 'change at the margins' (Handmer and Dovers 1996) without significant transformation of existing power structures and feedbacks.

Adapt, learn, change, reorganise

These terms are widely used in resilience definitions, but the degree of change is often to be tempered by a parallel requirement to maintain the existing system and functions. This implies incremental change that reinforces the status quo.

Transformation

Transformation involves change to feedbacks, functions and structures, that is, lowering the resilience of an undesirable resilience régime and moving to a more desirable one. It is therefore in opposition to a resilient status quo.

Transformation is rarely used in disaster resilience definitions, an exception being the International Panel on Climate Change (IPCC 2014). The IPCC definition requires systems to remain essentially the same while maintaining the 'capacity' for transformation. This ambiguous definition implies that while transformation should be possible, it should not actually take place.

Rapid recovery

This is a key element of engineering resilience. However, many have observed a tension between *rapid* recovery and *improved* recovery, which generally requires more time and money (e.g., Wright 2000; Kates *et al.* 2006). One solution is to plan for windows of opportunity so that administrative arrangements, resourcing and approvals are already in place.

2. Resistance language in text

As well as appearing in definitions, resistance wording was sometimes used in text, particularly in Australia and the USA. References that connected the words 'withstand', 'resist', or 'protect' to resilience in text included for Australia: (COAG 2009; Australian Government 2010*b*; COAG 2011; QRA 2011*b*; AGD 2012*a*; AGD 2012*b*; COAG 2012; QRA 2012*b*; State of Victoria 2012*a*; AGD 2013; DAE 2013; Queensland Government 2014*b*; State of Victoria 2015); and for the USA: (ASCE 2009; IPET 2009; NRC 2012*b;* ASCE 2013; CNY 2013; HSRTF 2013).

3. Discussion on the use of resilience definitions

Dictionary definitions from English language speaking countries reveal a strong influence of engineering-inspired interpretations of resilience. This means that public understanding about resilience will be coloured by engineering interpretations. Academic interpretations of disaster resilience tend to derive more from ecological systems research (which disputes the ideal of a stable state). The lack of systems-inspired dictionary definitions of resilience has implications not only for the public understanding of disaster resilience but also the application and communication of resilience by bureaucrats, politicians and policymakers in the emergency management sector.

There is a notable lack of consistency of definitions between and within documents, especially in the USA and Australia. Documents were found to contain up to three definitions with slightly different wording. The lack of consistency between resilience definitions is a well-discussed theme in disaster resilience studies, although most studies focus on theoretical rather than operational definitions.

3.1 Global

Global definitions exhibit a division, whereby sources with an emergency management outlook generally include 'resistance' terms but climate change adaptation related sources do not. This division is less clear in other case studies.

The UNISDR is highly influential in setting the disaster resilience agenda globally and some organisations use the UNISDR definitions in preference to local ones. Examples include a paper written by government officials from the Netherlands (Weieriks and Vlaanderen 2015), an early USA report (SDR 2005), and the Deloitte Australian Business Roundtable for Disaster Resilience (DAE 2013; DAE 2014). DAE's stated focus (p.5) is on the pre-disaster 'resist' component of the UNISDR (2009) definition. DAE supports resistant measures, such as dams, levees and building standards. It also supports non-structural options including information, incentives and methodologies to support decision-making; land use planning; and preparedness.

3.2 USA

In the USA, resistance terms appear in almost every definition, and where this is not the case, resistance language is often used when describing resilience in the text (e.g. CNY 2013, pages 7, 39; see also global UNISDR 2015*c* S.17). Executive orders and presidential policy directives often reflect the prevent/mitigate-prepare-respond-recover (PPRR) framework in resilience definitions, with 'anticipation' sometimes added and mitigate/prevent becoming adapt.

3.4 UK

Of the UK definitions, most incorporate resistance terminology.

3.5 China and the Netherlands

These are both countries where 'resilience' is not a local word and understanding has to be gained from elsewhere. No disaster resilience definitions were provided by Chinese sources and few resilience definitions appear documents from the Netherlands. Some definitions derive from overseas sources (the UNISDR and USA). An early Netherlands definition focuses on the engineering ideal of rapid recovery, which is interesting as overall recovery did not rate as highly as most other categories in the Netherlands study results. Sources with the rapid recovery definition were concerned with modifying the existing flood defence system to enable minimal damage and rapid recovery in the event of failure. One definition draws upon systems theory.

3.6 Australia

Australian disaster resilience definitions demonstrate a close relationship with the prevent-prepare-respond-recover (PPRR) framework, which encompasses resistance measures. Resistance terminology is common in pseudo-definitions.

Australian policy documents frequently choose not to define resilience, even when it is a central concept (DOTARS 2004; COAG 2011; State of Queensland 2011; State of Victoria 2012*a*; AGD 2013). The primary definition for some sources, including legal agreements, is based on the PPRR framework (COAG 2009; QRA 2011*b*; COAG 2014). An alternative de facto definition appears in the text of many documents relating to the National Strategy for Disaster Resilience: "capacity to withstand and recover from emergencies and disasters" (COAG 2011; QRA 2011*b*; State of Queensland 2011; AGD 2013). While technically using the COAG 2009 definition, the Queensland Reconstruction Authority (QRA 2011*b*) prominently displays the words "The capacity to prepare for, withstand, respond to and recover from disasters" on title pages and in the footer of every double page. This suggests that while wishing to use a national definition, the QRA did not entirely agree with it. It therefore created its own *de facto* resilience definition by amending the de facto COAG 2011 definition (which it also cites).

While it may be a coincidence, similarity was noted between the Queensland (Queensland Government 2014*c*) and USA (White House 2013*c*) definitions, between the UK Pitt review definition (Pitt 2008:240) and Australia's COAG 2011 pseudo-definition.

Supplement 2: Measures linked to resilience by case study sources

The standard Prevent-Prepare-Respond-Recover (PPRR) framework was modified for the purposes of this study. The revised framework incorporates an ‘anticipate’ category and restructures prevent/mitigate and prepare categories.

Although definitions of resilience often emphasise the ability to recover, this presupposes the ability to anticipate and put in place measures prior to disasters taking place. Anticipation is therefore associated with resilience by both theorists and policymakers (e.g., Pelling 2003; UNISDR 2015*c*). As discussed in the text introduction, the lack of an ‘anticipate’ category is also a common criticism of the standard PPRR framework.

The generic term ‘flood mitigation’ covers an array of measures, and does not distinguish between measures of varying adaptive potential, including the relative emphasis placed on ‘resistance’ style measures, such as flood barriers. In order to analyse resilience interpretations, the prevent/mitigate category therefore required further refinement. Measures were therefore divided into the broad categories: ‘avoid’ (e.g., avoiding development in high hazard areas via zoning); ‘exposure reduction’ (e.g., engineering measures that reduce likelihood of exposure); and ‘accommodate’ (which allows flooding, or acknowledges it will occur, but aims to minimise damages). ‘Accommodate’ was further subdivided into ‘built environment’, ‘ecosystems-based’ and ‘prepare’ (the latter being a category in its own right in the standard PPRR framework).

The ‘respond’ category includes activities relating to response capacity and capability (these terms are defined in Supplement 1). Activities relating to response and recovery planning are included under ‘prepare’.

Broad categories were divided into activities, and wording aimed to reflect that used by various source documents. The activity inclusions and wording thus evolved as work progressed and references were re-checked to ensure consistency. Where possible, the framework distinguishes between transformational and incremental or status quo measures. However, the difference is not always obvious and as discussed under the section ‘resilience and adaptability’, much depends on underlying objectives and philosophies.

Tables S.7.2 and S.7.3 show ‘categories’ in caps (e.g., ANTICIPATE) and ‘activities’ in sentence case (e.g., Vulnerability mapping). The term ‘activities’ also includes ideas and mindsets such as shared responsibility.

Table S.7.2: The percentage of source documents linking activities to resilience.

	China	NL	AUST	USA	Global
ANTICIPATE					
Vulnerability mapping and assessment; vulnerability or resilience indicators	33%	43%	48%	39%	86%
Hazard information (e.g., flood studies, modelling, mapping, disaster loss data); consistent methodologies; accessibility	22%	5%	77%	57%	90%
Hazard monitoring, forecasting and warning systems	33%	38%	58%	30%	76%
Climate change adaptation strategies(may specify qualities such as: long-term view; iterative; flexible; no regrets; robust)	33%	76%	48%	70%	95%
Risk assessment; risk management assessment and plans	22%	29%	94%	74%	76%
Decision support systems for avoiding / mitigating (including access to information, trade-off and synergy evaluation)	22%	10%	45%	48%	43%
Investigate / understand underlying disaster causes† (e.g., inequity; population growth; climate change; land degradation; human intervention; terms of trade; urbanisation)	78%	71%	26%	48%	67%
Foster an adaptive learning culture (e.g., Research, innovation; post-disaster review; reassess strategies, values, institutions; lesson learning)	11%	52%	61%	70%	71%
AVOID					
Land use planning and management, land use zoning and enforcement	33%	67%	87%	43%	76%
Land use change (as part of urban renewal or transition)	0%	57%	32%	22%	43%
Climate change mitigation to avoid increased disaster risk (emissions reduction / sequestration)	0%	10%	0%	22%	38%
EXPOSURE REDUCTION					
Flood barriers (e.g., levees, flood gates)	33%	19%	48%	26%	62%
Diversion (e.g., channels)	0%	10%	6%	4%	19%
Artificial flood storage (e.g., flood storage dams)	0%	5%	19%	9%	29%
Rapid drainage (e.g., deeper, wider, concreted, straightened drains; backflow prevention; vegetation removal)	11%	5%	26%	9%	48%
Channel / foreshore stabilization (e.g., concrete lining, groynes)	11%	5%	16%	17%	29%
Energy dissipation structures (e.g., bulkheads, breakwaters, artificial reefs)	0%	5%	3%	17%	10%

EXPOSURE REDUCTION [subset: INCREMENTAL IMPROVMENT]					
[of engineered structures] Improved design; heightening; whole system planning, administration, maintenance, financing, operation, education, legislation, enforcement	33%	43%	13%	35%	38%
ACCOMMODATE [subset: BUILT ENVIRONMENT]					
Resistant construction standards; enforcement (e.g., water or wind velocity; fire; quake; floodproofing)	11%	24%	81%	57%	76%
Accommodating construction standards; enforcement (e.g., raised above; water flow below; moveable; temporary)	22%	38%	81%	52%	76%
Urban design (e.g., SUDS; evacuation routes; zoning and standards for flood compatibility, including critical infrastructure, hazardous substances)	22%	14%	32%	35%	38%
ACCOMMODATE [subset: ECOSYSTEM BASED]					
Reduced reliance on structural approaches; an appropriate balance	0%	10%	0%	0%	10%
'Living with Floods': mindset of working with ecological processes (rather than fighting them)	33%	38%	3%	0%	14%
Room for rivers to flood; expand area for temporary flooding; dyke removal or relocation; reconnect floodways	33%	71%	3%	22%	33%
Protecting / enhancing natural flow paths and flood buffers: wetlands, riparian and coastal ecosystems	33%	48%	32%	52%	81%
IWRM, co-benefits, multiple use and supporting governance arrangements	0%	48%	3%	26%	38%
Regional / catchment-based data and planning	11%	24%	23%	4%	33%
Basin land management (e.g., erosion control; permeability; agricultural practices)	11%	5%	6%	9%	38%
Public education / understanding of hydrology, ecosystems, catchment / human interactions	0%	14%	0%	0%	24%
ACCOMMODATE [subset: PREPARE]					
Awareness of risks and knowledge of what to do before and during an emergency	22%	24%	84%	39%	62%
Foster adaptive capacity through allowing exposure to hazard or disturbance	22%	5%	0%	0%	10%

Capacity building (e.g., fostering networks; partnerships; volunteering; stakeholder participation; empowerment; sharing knowledge, skills, information, resources, technology)	11%	43%	65%	43%	90%
Shared responsibility (individuals, businesses, communities, governments); self-reliance; safety behavioural / cultural change	11%	5%	61%	30%	19%
Reducing vulnerability of disadvantaged groups (e.g., social equity; health; education; inclusion; land tenure; sustainable development; food security)	22%	19%	39%	22%	90%
Institutional arrangements (e.g., agencies, leadership, roles, responsibilities, coordination; accountabilities; policy integration; laws; incentives; funding; investment policies; before, during, after disasters)	33%	43%	74%	78%	86%
Business continuity planning; capacity of critical infrastructure and services to function in disasters; redundancy; substitutability	11%	14%	77%	61%	62%
Multi-hazard disaster management planning (e.g., by households, business, public sector and emergency management agencies)	22%	24%	55%	22%v	67%
Evacuation planning, infrastructure and supplies	33%	29%	26%	17%	52%
Planning for/preventing disaster-related epidemics	11%	0%	3%	9%	14%
Recovery planning	11%	5%	32%	22%	43%
Anticipatory transformational recovery planning; windows of opportunity	0%	14%	0%	0%	29%
RESPOND					
Information and communication systems, strategies	11%	10%	32%	26%	33%
Response capacity, capability and flexibility (local and scaled-up; staff; equipment; emergency supplies; skills; shelters; operation centres; interoperability and redundancy)	11%	10%	55%	30%	71%
Drills and scenario simulations, training	11%	5%	19%	22%	38%
Decision support systems for response management	11%	0%	6%	4%	0%
Volunteer recruitment, training and support	11%	5%	39%	0%	29%

RECOVER					
Financing recovery (e.g., insurance; maintaining insurance affordability / availability; charity; public relief and recovery funding; 'risk sharing' compensation; loans; subsidies; local labour; mitigation incentives)	33%	24%	48%	30%	67%
Post-disaster needs assessment; local participation	0%	0%	23%	26%	38%
RECOVER [subset: BOUNCE BACK TO PRE-EXISTING STANDARDS]					
Rapid rebuild to prior standards	11%	19%	10%	13%	29%
Non-financial recovery support (e.g., long term health; rebuilding communities)	0%	0%	19%	22%	29%
Recovery of existing industries	11%	0%	10%	22%	24%
Ecosystem recovery	11%	5%	10%	26%	5%
RECOVER [subset: INCREMENTAL IMPROVEMENT]					
Improved rebuild or post-disaster upgrade	11%	19%	29%	48%	52%
Adjustment of existing industries; diversification‡	11%	0%	10%	9%	52%
RECOVER [subset: TRANSFORMATIONAL CHANGE]					
Relocation; land use change (as part of recovery)‡	11%	0%	13%	17%	33%
New, flood compatible industries; alternative livelihoods‡	0%	0%	0%	0%	10%
Recovery targeting long term improvements for the most vulnerable	0%	0%	0%	13%	48%

† Transformational approaches often address underlying causes. For inclusion in this activity, the document had to either recommend this be done or the document itself provide an examination of one or more underlying cause. Documents that merely listed underlying causes in a preamble or rationale were not included (else this activity would be meaningless as most policy documents include a brief rationale).

‡These are 'build back better' activities that have greatest chance of uptake following a disaster. However, they may also be pre-emptive strategies initiated outside the recovery phase. *Voluntary relocation*, in particular, tends to be a measure implemented over many decades. *Alternative livelihoods* is a form of land use change aimed at both avoiding flood damage (abandoning the previous flood-susceptible land use) and accommodating floods (through the new flood tolerant land use). *Diversification* could be pursued as a continuity strategy undertaken on an individual business or broader economic scale (preparation). The recovery phase is sometimes used as a 'window of opportunity' to implement these changes (this generally requires pre-planning and supportive institutional arrangements as the opportunity is brief).

Table S.2.3: Source documents linking activities to resilience

	China	NL	Australia	USA	Global
ANTICIPATE					
Vulnerability mapping and assessment; vulnerability or resilience indicators	(Liao 2012) (Xiao *et al*. 2014) (Gao *et al*. 2014)	(de Bruijn 2004*a*) (de Bruijn 2004*b*) (Klijn *et al.*, 2004) (NEAA 2009) (Dutch Government 2009) (Mens *et al*. 2011) (van Slobbe *et al*. 2013) (Weieriks and Vlaanderen 2015) (Mens *et al*. 2015)	(COAG 2007) (DCC 2009) (COAG 2011) (QRA 2011*b*) (State of Queensland 2011) (NEMC 2012) (AGD 2012*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (DAE 2013) (Queensland Government 2014*b*) (Queensland Government 2014*c*) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014)	(NRC 2012*b*) (DHS 2013) (CNY 2013) (HSRTF 2013) (White House 2013*a*) (White House 2013*b*) (White House 2013*c*) (White House 2014) (FEMA 2015*b*)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (GEF 2015*b*) (O'Connell *et al*. 2015) (WB 2015) (ADB 2015)
Hazard information (e.g., flood studies, modelling, mapping, disaster loss data); consistent methodologies; accessibility	(CMPG 2012) (Jiang *et al*. 2013)	(Weieriks and Vlaanderen 2015)	(DOTARS 2004) (MCPEM-EM 2008) (Australian Government 2010*b*) (State of Queensland 2010) (State of Queensland 2011) (QRA 2011*b*) (COAG 2011) (COAG 2012) (NEMC 2012) (AGD 2012*a*) (AGD 2012*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (Queensland Government 2014*b*)	(IPET 2009) (DHS 2011) (NRC 2012*a*) (NRC 2012*b*) (CPRA 2012) (CNY 2013) (DHS 2013) (White House 2013*b*) (White House 2013*c*) (ASCE 2013) (White House 2015*a*) (FEMA 2015*a*) (FEMA 2015*b*)	(UNISDR 2005) (UNFCCC 2009) (UNEP 2010*b*) (UNISDR 2012*a*) (GFDRR 2012) (UN 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (O'Connell *et al*. 2015) (WB 2015) (ADB 2015)

			(Queensland Government 2014*c*) (Queensland Government 2014*d*) (State of Victoria 2014*a*) (State of Victoria 2014*b*) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014)		
Hazard monitoring, forecasting and warning systems	(CMPG 2012) (Jiang *et al*. 2013) (Lu and Lewis 2015)	(Vis *et al*. 2003) (de Bruijn 2004*a*) (de Bruijn 2004*b*) (Klijn *et al*. 2004) (NEAA 2011) (Engel *et al*. 2014) (Dutch Government 2014) (Weieriks and Vlaanderen 2015)	(DOTARS 2004) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (NEMC 2012) (AGD 2012*a*) (AGD 2012*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (Queensland Government 2014*b*) (Queensland Government 2014*c*) (Queensland Government 2014*d*) (State of Victoria 2014*a*) (Productivity commission 2014*b*) (DAE 2014) (State of Victoria 2015)	(DHS 2011) (NRC 2012*a*) (NRC 2012*b*) (HSRTF 2013) (White House 2013*b*) (White House 2013*c*) (USACE 2013)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (UN 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (ADB 2015)
Climate change adaptation strategies (may specify qualities such as: long-term view; iterative; flexible; no regrets; robust)	(Liao 2012) (Jiang *et al*. 2013) (Lu and Lewis 2015)	(Dutch Government 2000) (de Bruijn 2004*a*) (Klijn *et al*. 2004) (Wolsink 2006) (Smits *et al*. 2006)	(COAG 2007) (MCPEM-EM 2008) (MCPEM-EM 2009) (DCC 2009) (State of Queensland 2010) (COAG 2011)	(White House 2010) (NRC 2012*b*) (CPRA 2012) (DHS 2013) (CNY 2013) (HSRTF 2013) (White House 2013*a*) (White House 2013*b*)	(UNISDR 2005) (UNFCCC 2009) (UNEP 2010*b*) (UNISDR 2012*a*) (GFDRR 2012) (UN 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012)

		(Dutch Government 2009) (NEAA 2009) (NEAA 2011) (Dutch Government 2012) (De Boer and Bressers 2011*b*) (Nijssen 2012) (van Slobbe *et al*. 2013) (Dutch Government 2013) (Zevenbergen *et al*. 2013) (Dutch Government 2014) (Weieriks and Vlaanderen 2015)	(State of Queensland 2011) (QRA 2011*b*) (COAG 2012) (State of Victoria 2013*a*) (DAE 2013) (Queensland Government 2014*b*) (State of Victoria 2014*a*) (State of Victoria 2014*b*) (DAE 2014)	(USACE 2013) (White House 2014) (White House 2015*a*) (White House 2015*b*) (FEMA 2015*a*) (FEMA 2015*b*) (GAO 2015) (Thomas and DeWeese 2015)	(Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (GEF 2015*a*) (GEF 2015*b*) (O'Connell *et al*. 2015) (WB 2015) (ADB 2015)
Risk assessment; risk management assessment and plans	(CMPG 2012) (Jiang *et al*. 2013)	(Vis *et al*. 2003) (Klijn *et al*. 2004) (Dutch Government 2013) (Zevenbergen *et al*. 2013) (Dutch Government 2014) (Weieriks and Vlaanderen 2015)	(DOTARS 2004) (COAG 2007) (MCPEM-EM 2008) (COAG 2009) (MCPEM-EM 2009) (AGD 2009) (DCC 2009) (Australian Government 2010*b*) (State of Queensland 2010) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (COAG 2012) (NEMC 2012) (AGD 2012*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (COAG 2014) (Queensland Government 2014*b*)	(IPET 2009) (ASCE 2009) (DHS 2011) (NRC 2012*a*) (NRC 2012*b*) (CPRA 2012) (DHS 2013) (CNY 2013) (HSRTF 2013) (White House 2013*a*) (White House 2013*b*) (White House 2013*c*) (ASCE 2013) (White House 2014) (FEMA 2015*a*) (FEMA 2015*b*) (GAO 2015)	(UNISDR 2005) (UNISDR 2012*a*) (GFDRR 2012) (UN 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (GEF 2015*a*) (WB 2015) (ADB 2015)

			(Queensland Government 2014*c*) (Queensland Government 2014*d*) (State of Victoria 2014*a*) (State of Victoria 2014*b*) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014)		
Decision support systems for avoiding / mitigating (including access to information, trade-off and synergy evaluation)	(Cai *et al*. 2011) (Jiang *et al*. 2013)	(de Bruijn 2004*b*) (Dutch Government 2014)	(DOTARS 2004) (DCC 2009) (Australian Government 2010*b*) (COAG 2011) (State of Queensland 2011) (AGD 2012*b*) (QRA 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (Queensland Government 2014*b*) (State of Victoria 2014*b*) (Productivity commission 2014*b*) (DAE 2014)	(DHS 2011) (NRC 2012*a*) (NRC 2012*b*) (CPRA 2012) (CNY 2013) (HSRTF 2013) (White House 2013*a*) (White House 2014) (USACE 2013) (GAO 2015) (FEMA 2015*b*)	(UNISDR 2005) (IPCC 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (O'Connell *et al*. 2015)
Investigate / understand underlying disaster causes† (e.g., inequity; population growth; climate change; land degradation; human intervention; terms of trade; urbanisation)	(Cheng 2006) (Cai *et al*. 2011) (Liao 2012) (Jiang *et al*. 2013) (Gao *et al*. 2014) (Xiao *et al*. 2014) (Lu and Lewis 2015)	(Dutch Government 2000) (de Bruijn 2004*a*) (de Bruijn 2004*b*) (Klijn *et al*. 2004) (Wolsink 2006) (Smits *et al*. 2006) (NEAA 2009) (Dutch Government 2009)	(MCPEM-EM 2009) (DCC 2009) (COAG 2011) (State of Queensland 2011) (AGD 2013) (DAE 2013) (Productivity commission 2014*b*) (State of Victoria 2015)	(IPET 2009) (NRC 2012*b*) (CPRA 2012) (CNY 2013) (HSRTF 2013) (White House 2013*a*) (White House 2013*b*) (ASCE 2013) (White House 2015*b*) (FEMA 2015*b*) (Thomas and DeWeese 2015)	(UNEP 2010*b*) (GFDRR 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (GEF 2015*a*) (O'Connell *et al*. 2015) (WB 2015) (ADB 2015)

		(De Boer and Bressers 2011*b*) (NEAA 2011) (Dutch Government 2013) (van Slobbe *et al*. 2013) (Zevenbergen *et al*. 2013) (Engel *et al*. 2014) (Weieriks and Vlaanderen 2015)			
Foster an adaptive learning culture (e.g., Research, innovation; post-disaster review; reassess strategies, values, institutions; lesson learning)	(Liao 2012)	(Klijn *et al*. 2004) (Wolsink 2006) (Smits *et al*. 2006) (NEAA 2009) (Dutch Government 2009) (De Boer and Bressers 2011*b*) (van Slobbe *et al*. 2013) (Dutch Government 2013) (Zevenbergen *et al*. 2013) (Engel *et al*. 2014) (Dutch Government 2014) (Weieriks and Vlaanderen 2015)	(DOTARS 2004) (MCPEM-EM 2008) (MCPEM-EM 2009) (DCC 2009) (Australian Government 2010*b*) (COAG 2011) (NEMC 2012) (AGD 2012*b*) (COAG 2012) (QRA 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (Queensland Government 2014*b*) (State of Victoria 2014*a*) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014) (State of Victoria 2015)	(IPET 2009) (ASCE 2009) (White House 2010) (NRC 2012*b*) (DHS 2013) (USACE 2013) (CNY 2013) (HSRTF 2013) (White House 2013*a*) (White House 2013*b*) (White House 2013*c*) (ASCE 2013) (White House 2014) (White House 2015*a*) (FEMA 2015*a*) (FEMA 2015*b*)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (GEF 2015*a*) (O'Connell *et al*. 2015) (WB 2015) (ADB 2015)
AVOID					
Land use planning and management, land use zoning and enforcement	(Cheng 2006) (Jiang *et al*. 2013) (Huang *et al*. 2013)	(Dutch Government 2000) (Vis *et al*. 2003) (de Bruijn 2004*a*) (de Bruijn 2004*b*)	(DOTARS 2004) (COAG 2007) (DCC 2009) (AGD 2009) (State of Queensland 2010) (COAG 2011)	(DHS 2011) (NRC 2012*a*) (NRC 2012*b*) (DHS 2013) (USACE 2013) (CNY 2013) (HSRTF 2013) (White House 2015*a*) (FEMA 2015*a*)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (UN 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012)

		(Klijn *et al*. 2004) (Wolsink 2006) (Smits *et al*. 2006) (NEAA 2009) (NEAA 2011) (De Boer and Bressers 2011*b*) (van Slobbe *et al*. 2013) (Zevenbergen *et al*. 2013) (Dutch Government 2014) (Weieriks and Vlaanderen 2015)	(State of Queensland 2011) (QRA 2011*b*) (COAG 2012) (NEMC 2012) (AGD 2012*a*) (AGD 2012*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (COAG 2014) (Queensland Government 2014*b*) (Queensland Government 2014*c*) (Queensland Government 2014*d*) (State of Victoria 2014*a*) (State of Victoria 2014*b*) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014) (State of Victoria 2015)	(FEMA 2015*b*)	(Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (ADB 2015)
Land use change (as part of urban renewal or transition)	0	(Vis *et al*. 2003) (de Bruijn 2004*a*) (Klijn *et al*. 2004) (Wolsink 2006) (Smits *et al*. 2006) (NEAA 2009) (De Boer and Bressers 2011*b*) (NEAA 2011) (Nijssen 2012) (Zevenbergen *et al*. 2013) (Dutch Government 2014)	(DOTARS 2004) (State of Queensland 2011) (NEMC 2012) (QRA 2012*a*) (AGD 2013) (DAE 2013) (Queensland Government 2014*c*) (Queensland Government 2014*d*) (Productivity commission 2014*b*) (Barnes *et al*. 2014)	(NRC 2012*a*) (NRC 2012*b*) (CPRA 2012) (USACE 2013) (CNY 2013)	(UNEP 2010*b*) (UNISDR 2012*a*) (IPCC 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (IPCC 2014) (UNISDR 2015*a*) (O'Connell *et al*. 2015)

		(Weieriks and Vlaanderen 2015)			
Climate change mitigation to avoid increased disaster risk (emissions reduction / sequestration)	0	(NEAA 2009) (Dutch Government 2013)	0	(NRC 2012*b*) (White House 2013*a*) (White House 2013*b*) (CNY 2013) (White House 2014)	(UNISDR 2012*a*) (IPCC 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*)
EXPOSURE REDUCTION					
Flood barriers (e.g., levees, flood gates)	(CMPG 2012) (Gao *et al*. 2014) (Lu and Lewis 2015)	(NEAA 2011) (Zevenbergen *et al*. 2013) (Dutch Government 2014) (Mens *et al*. 2015)	(DOTARS 2004) (AGD 2009) (State of Queensland 2011) (AGD 2012*a*) (NEMC 2012) (QRA 2012*a*) (AGD 2013) (DAE 2013) (Queensland Government 2014*b*) (Queensland Government 2014*c*) (Queensland Government 2014*d*) (State of Victoria 2014*a*) (State of Victoria 2014*b*) (Productivity commission 2014*b*) (Barnes *et al*. 2014)	(NRC 2012*b*) (USACE 2013) (CNY 2013) (FEMA 2015*b*) (Thomas and DeWeese 2015) (GAO 2015)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (ADB 2015)
Diversion (e.g., channels)	0	(Nijssen 2012) (Mens *et al*. 2015)	(DOTARS 2004) (AGD 2013)	(USACE 2013)	(UNFCCC 2009) (Jha *et al*. 2012) (UNEP 2014) (UNISDR 2015*a*)
Artificial flood storage (e.g., flood storage dams)	0	(Dutch Government 2014)	(DOTARS 2004) (QRA 2012*a*) (AGD 2013) (DAE 2013)	(USACE 2013) (FEMA 2015*b*)	(UNISDR 2005) (UNISDR 2012*a*) (IPCC 2012) (GEF 2012)

			(Productivity commission 2014*b*) (Barnes *et al*. 2014)		(Jha *et al*. 2012) (UNEP 2014)
Rapid drainage (e.g., deeper, wider, concreted, straightened drains; backflow prevention; vegetation removal)	(Lu and Lewis 2015)	(NEAA 2011)	(DOTARS 2004) (State of Queensland 2011) (QRA 2012*a*) (AGD 2013) (DAE 2013) (Queensland Government 2014*c*) (State of Victoria 2014*b*) (Productivity commission 2014*b*)	(CNY 2013) (GAO 2015)	(UNISDR 2012*a*) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (ADB 2015)
Channel / foreshore stabilization (e.g., concrete lining, groynes)	(Lu and Lewis 2015)	(Dutch Government 2014)	(DOTARS 2004) (State of Queensland 2011) (QRA 2012*a*) (Queensland Government 2014*c*) (Queensland Government 2014*d*)	(NRC 2012*a*) (USACE 2013) (CNY 2013) (FEMA 2015*b*)	(UNFCCC 2009) (IPCC 2012) (GEF 2012) (Jha *et al*. 2012) (IPCC 2014) (UNEP 2014)
Energy dissipation structures (e.g., bulkheads, breakwaters, artificial reefs)	0	(Dutch Government 2014)	(DAE 2013)	(USACE 2013) (CNY 2013) (HSRTF 2013) (FEMA 2015*b*)	(IPCC 2012) (GEF 2012)
EXPOSURE REDUCTION [subset: INCREMENTAL IMPROVMENT]					
[of engineered structures] Improved design; heightening; whole system planning, administration, maintenance, financing, operation, education, legislation, enforcement	(Huang *et al*. 2013) (Gao *et al*. 2014) (Lu and Lewis 2015)	(Vis *et al*. 2003) (de Bruijn 2004*a*) (de Bruijn 2004*b*) (Klijn *et al*. 2004) (Wolsink 2006) (Smits *et al*. 2006) (NEAA 2009) (Dutch Government 2014) (Mens *et al*. 2015)	(DOTARS 2004) (AGD 2013) (State of Victoria 2013*a*) (Queensland Government 2014*b*)	(IPET 2009) (ASCE 2009) (NRC 2012*a*) (USACE 2013) (CNY 2013) (ASCE 2013) (FEMA 2015*b*) (Thomas and DeWeese 2015)	(UNEP 2010*b*) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha et al. 2012) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*)

ACCOMMODATE [subset: BUILT ENVIRONMENT]					
Resistant construction standards; enforcement (e.g., water or wind velocity; fire; quake; floodproofing)	(Cheng 2006)	(Vis *et al*. 2003) (de Bruijn 2004*a*) (Nijssen 2012) (Zevenbergen *et al*. 2013) (Engel *et al*. 2014)	(DOTARS 2004) (COAG 2007) (DCC 2009) (AGD 2009) (State of Queensland 2010) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (NEMC 2012) (AGD 2012*a*) (AGD 2012*b*) (COAG 2012) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (Queensland Government 2014*b*) (Queensland Government 2014*c*) (Queensland Government 2014*d*) (State of Victoria 2014*b*) (COAG 2014) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014)	(ASCE 2009) (NRC 2012*b*) (CPRA 2012) (DHS 2013) (USACE 2013) (CNY 2013) (HSRTF 2013) (White House 2013*b*) (White House 2013*c*) (ASCE 2013) (FEMA 2015*a*) (FEMA 2015*b*) (GAO 2015)	(UNISDR 2005) (UNFCCC 2009) (UNEP 2010*b*) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (ADB 2015)
Accommodating construction standards; enforcement (e.g., raised above; water flow below; moveable; temporary)	(Liao 2012) (Jiang *et al*. 2013)	(Vis *et al*. 2003) (Klijn *et al*. 2004) (Smits *et al*. 2006) (NEAA 2011) (Nijssen 2012) (Dutch Government 2013) (Zevenbergen *et al*. 2013)	(DOTARS 2004) (COAG 2007) (DCC 2009) (AGD 2009) (State of Queensland 2010) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (AGD 2012*a*) (NEMC 2012) (AGD 2012*b*)	(NRC 2012*b*) (CPRA 2012) (USACE 2013) (CNY 2013) (HSRTF 2013) (White House 2013*b*) (ASCE 2013) (White House 2015*a*) (FEMA 2015*a*) (FEMA 2015*b*) (Thomas and DeWeese 2015)	(UNISDR 2005) (UNFCCC 2009) (UNEP 2010*b*) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014)

		(Engel *et al*. 2014)	(COAG 2012) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (Queensland Government 2014*b*) (Queensland Government 2014*c*) (Queensland Government 2014*d*) (State of Victoria 2014*b*) (COAG 2014) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014)	(GAO 2015)	(IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (ADB 2015)
Urban design (e.g., SUDS; evacuation routes; zoning and standards for flood compatibility, including critical infrastructure, hazardous substances)	(Liao 2012) (Lu and Lewis 2015)	(NEAA 2011) (Dutch Government 2013) (Dutch Government 2014)	(DOTARS 2004) (DCC 2009) (AGD 2009) (State of Queensland 2010) (State of Queensland 2011) (NEMC 2012) (QRA 2012*a*) (AGD 2013) (Queensland Government 2014*c*) (DAE 2014)	(NRC 2012*a*) (NRC 2012*b*) (DHS 2013) (CNY 2013) (HSRTF 2013) (White House 2013*c*) (FEMA 2015*a*) (FEMA 2015*b*)	(UNISDR 2012*a*) (IPCC 2012) (IPCC 2014) (Jha *et al*. 2012) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (ADB 2015)
ACCOMMODATE [subset: ECOSYSTEM BASED]					
Reduced reliance on structural approaches; an appropriate balance	0	(Wolsink 2006) (Zevenbergen *et al*. 2013) 2	0	0	(UNISDR 2012*a*) (Jha *et al*. 2012) 2
'Living with Floods': mindset of working with ecological processes (rather than fighting them)	(Cheng 2006) (Liao 2012) (Jiang *et al*. 2013)	(Vis *et al*. 2003) (de Bruijn 2004*a*) (Klijn *et al*. 2004) (Wolsink 2006)	(QRA 2012*a*)	0	(Jha *et al*. 2012) (WB and GFDRR 2013) (UNISDR 2015*a*)

		(Smits *et al*. 2006) (Nijssen 2012) (van Slobbe *et al*. 2013) (Engel *et al*. 2014)			
Room for rivers to flood; expand area for temporary flooding; dyke removal or relocation; reconnect floodways	(Liao 2012) (Jiang *et al*. 2013) (Huang *et al*. 2013)	(Dutch Government 2000) (Vis *et al*. 2003) (de Bruijn 2004*a*) (de Bruijn 2004*b*) (Klijn *et al*. 2004) (Wolsink 2006) (Smits *et al*. 2006) (Dutch Government 2009) (De Boer and Bressers 2011*b*) (Nijssen 2012) (Dutch Government 2012) (van Slobbe *et al*. 2013) (Zevenbergen *et al*. 2013) (Dutch Government 2014) (Mens *et al*. 2015)	(DAE 2013)	(NRC 2012*a*) (NRC 2012*b*) (USACE 2013) (FEMA 2015*b*) (Thomas and DeWeese 2015)	(UNEP 2010*b*) (UNISDR 2012*a*) (IPCC 2012) (IPCC 2014) (Jha *et al*. 2012) (UNEP 2014) (UNISDR 2015*a*)
Protecting / enhancing natural flow paths and flood buffers: wetlands, riparian and coastal ecosystems	(Cai *et al*. 2011) (Huang *et al*. 2013) (Lu and Lewis 2015)	(Vis *et al*. 2003) (Klijn *et al*. 2004) (Smits *et al*. 2006) (NEAA 2009) (Dutch Government 2009) (De Boer and Bressers 2011*b*) (van Slobbe *et al*. 2013)	(DCC 2009) (State of Queensland 2010) (QRA 2011*b*) (QRA 2012*a*) (AGD 2013) (Queensland Government 2014*b*) (Queensland Government 2014*c*) (Queensland Government 2014*d*)	(NRC 2012*a*) (NRC 2012*b*) (CPRA 2012) (CNY 2013) (HSRTF 2013) (White House 2013*b*) (USACE 2013) (White House 2015*a*) (FEMA 2015*a*) (FEMA 2015*b*) (Thomas and DeWeese 2015) (GAO 2015)	(UNISDR 2005) (UNFCCC 2009) (UNEP 2010*b*) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (IPCC 2014) (UNEP 2014)

		(Dutch Government 2013) (Dutch Government 2014) (Weieriks and Vlaanderen 2015)	(State of Victoria 2014*a*) (Productivity commission 2014*b*)		(UNISDR 2015*a*) (UNISDR 2015*c*) (GEF 2015*a*) (O'Connell *et al*. 2015) (ADB 2015)
IWRM, co-benefits, multiple use and supporting governance arrangements	0	(Vis *et al*. 2003) (de Bruijn 2004*a*) (Klijn *et al*. 2004) (Wolsink 2006) (Smits *et al*. 2006) (De Boer and Bressers 2011*b*) (Nijssen 2012) (Dutch Government 2012) (van Slobbe *et al*. 2013) (Dutch Government 2014)	(Queensland Government 2014*b*)	(NRC 2012*a*) (NRC 2012*b*) (USACE 2013) (HSRTF 2013) (FEMA 2015*b*) (Thomas and DeWeese 2015)	(UNEP 2010*b*) (UNISDR 2012*a*) (IPCC 2012) (GEF 2012) (Jha *et al*. 2012) (IPCC 2014) (GEF 2015*a*) (WB 2015)
Regional / catchment-based data and planning	(CMPG 2012)	(Klijn *et al*. 2004) (Wolsink 2006) (Dutch Government 2009) (Nijssen 2012) (Dutch Government 2014)	(DCC 2009) (QRA 2011*b*) (NEMC 2012) (QRA 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (Queensland Government 2014*c*)	(FEMA 2015*b*)	(IPCC 2012) (GEF 2012) (GoJ and WB 2012) (IPCC 2014) (Jha *et al*. 2012) (UNISDR 2015*c*) (O'Connell *et al*. 2015)
Basin land management (e.g., erosion control; permeability; agricultural practices)	(Cai *et al*. 2011)	(Dutch Government 2013)	(QRA 2012*a*) (Queensland Government 2014*b*)	(NRC 2012*b*) (FEMA 2015*b*)	(UNISDR 2012*a*) (IPCC 2012) (GEF 2012) (Jha *et al*. 2012) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (ADB 2015)
Public education / understanding of hydrology,	0	(Smits *et al*. 2006) (van Slobbe *et al*. 2013)	0	0	(UNISDR 2012*a*) (IPCC 2012)

ecosystems, catchment / human interactions		(Engel *et al*. 2014)			(Jha *et al*. 2012) (IPCC 2014) (O'Connell *et al*. 2015)
ACCOMMODATE [subset: PREPARE]					
Awareness of risks and knowledge of what to do before and during an emergency	(CMPG 2012) (Jiang *et al*. 2013)	(de Bruijn 2004*a*) (de Bruijn 2004*b*) (Dutch Government 2014) (Engel *et al*. 2014) (Weieriks and Vlaanderen 2015)	(DOTARS 2004) (DCC 2009) (AGD 2009) (Australian Government 2010*b*) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (NEMC 2012) (AGD 2012*a*) (AGD 2012*b*) (COAG 2012) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (COAG 2014) (Queensland Government 2014*b*) (Queensland Government 2014*c*) (Queensland Government 2014*d*) (State of Victoria 2014*a*) (State of Victoria 2014*b*) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014) (State of Victoria 2015)	(White House 2010) (DHS 2011) (NRC 2012*a*) (NRC 2012*b*) (DHS 2013) (USACE 2013) (CNY 2013) (HSRTF 2013) (ASCE 2013)	(UNISDR 2005) (UNISDR 2012*a*) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (WB 2015)
Foster adaptive capacity through allowing exposure to hazard or disturbance	(Liao 2012) (Jiang *et al*. 2013)	(Engel *et al*. 2014)	0	0	(UNISDR 2015*a*) (O'Connell *et al*. 2015)

Capacity building (e.g., fostering networks; partnerships; volunteering; stakeholder participation; empowerment; sharing knowledge, skills, information, resources, technology)	(Cheng 2006)	(de Bruijn 2004*b*) (Wolsink 2006) (De Boer and Bressers 2011*b*) (Nijssen 2012) (van Slobbe *et al*. 2013) (Dutch Government 2013) (Engel *et al*. 2014) (Dutch Government 2014) (Weieriks and Vlaanderen 2015)	(DOTARS 2004) (Australian Government 2010*b*) (COAG 2011) (QRA 2011*b*) (State of Queensland 2011) (COAG 2012) (NEMC 2012) (AGD 2012*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (COAG 2014) (Queensland Government 2014*b*) (Queensland Government 2014*d*) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014) (State of Victoria 2015)	(White House 2010) (DHS 2011) (NRC 2012*a*) (NRC 2012*b*) (White House 2013*a*) (White House 2013*b*) (DHS 2013) (CNY 2013) (HSRTF 2013) (White House 2014)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (UN 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (GEF 2015*a*) (GEF 2015*b*) (O'Connell *et al*. 2015) (WB 2015) (ADB 2015)
Shared responsibility (individuals, businesses, communities, governments); self-reliance; safety behavioural / cultural change	(CMPG 2012)	(Engel *et al*. 2014)	(DOTARS 2004) (Australian Government 2010*b*) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (COAG 2012) (AGD 2012*a*) (AGD 2012*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (Queensland Government 2014*b*) (State of Victoria 2014*b*)	(White House 2011) (NRC 2012*a*) (NRC 2012*b*) (White House 2013*c*) (DHS 2013) (USACE 2013) (GAO 2015)	(UNISDR 2012*a*) (IPCC 2012) (WB and GFDRR 2013) (UNISDR 2015*c*)

			(Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014) (State of Victoria 2015)		
Reducing vulnerability of disadvantaged groups (e.g., social equity; health; education; inclusion; land tenure; sustainable development; food security)	Cheng 2006 (Liao 2012)	(de Bruijn 2004*b*) (Wolsink 2006) (Dutch Government 2013) (Weieriks and Vlaanderen 2015)	(DOTARS 2004) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (COAG 2012) (AGD 2012*b*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (COAG 2014) (State of Victoria 2014*a*) (DAE 2014)	(White House 2010) (NRC 2012*b*) (White House 2014) (FEMA 2015*b*) (Thomas and DeWeese 2015)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (UN 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (GEF 2015*a*) (GEF 2015*b*) (O'Connell *et al*. 2015) (WB 2015) (ADB 2015)
Institutional arrangements (e.g., agencies, leadership, roles, responsibilities, coordination; accountabilities; policy integration; laws; incentives; funding; investment policies; before, during, after disasters)	(Cai *et al*. 2011) (CMPG 2012) (Jiang *et al*. 2013)	(de Bruijn 2004*b*) (Wolsink 2006) (De Boer and Bressers 2011*b*) (van Slobbe *et al*. 2013) (Dutch Government 2013) (Zevenbergen *et al*. 2013) (Engel *et al*. 2014) (Dutch Government 2014) (Weieriks and Vlaanderen 2015)	(DOTARS 2004) (DCC 2009) (State of Queensland 2010) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (COAG 2012) (NEMC 2012) (AGD 2012*a*) (AGD 2012*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (COAG 2014) (Queensland Government 2014*b*)	(IPET 2009) (White House 2011) (DHS 2011) (NRC 2012*b*) (NRC 2012*a*) (DHS 2013) (CNY 2013) (HSRTF 2013) (White House 2013*a*) (White House 2013*b*) (White House 2013*c*) (USACE 2013) (ASCE 2013) (White House 2014) (White House 2015*a*) (FEMA 2015*a*) (Thomas and DeWeese 2015)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (GEF 2015*a*) (GEF 2015*b*) (O'Connell *et al*. 2015) (WB 2015) (ADB 2015)

			(State of Victoria 2014*a*) (State of Victoria 2014*b*) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014) (State of Victoria 2015)	(GAO 2015)	
Business continuity planning; capacity of critical infrastructure and services to function in disasters; redundancy; substitutability	(Liao 2012)	(de Bruijn 2004*b*) (NEAA 2009) (Weieriks and Vlaanderen 2015)	(DOTARS 2004) (AGD 2009) (Australian Government 2010*b*) (State of Queensland 2010) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (NEMC 2012) (AGD 2012*a*) (AGD 2012*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (Queensland Government 2014*b*) (Queensland Government 2014*c*) (Queensland Government 2014*d*) (State of Victoria 2014*a*) (State of Victoria 2014*b*) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014) (State of Victoria 2015)	(IPET 2009) (ASCE 2009) (White House 2010) (DHS 2011) (NRC 2012*b*) (DHS 2013) (CNY 2013) (HSRTF 2013) (White House 2013*a*) (White House 2013*b*) (White House 2013*c*) (FEMA, 2015*a*) (FEMA 2015*b*) (GAO 2015)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (ADB 2015)
Multi-hazard disaster	(Cheng 2006)	(de Bruijn 2004*b*)	(State of Queensland 2010)	(ASCE 2009) (White House 2011)	(UNISDR 2005) (UNFCCC 2009)

management planning (e.g., by households, business, public sector and emergency management agencies)	(Jiang *et al*. 2013)	(Zevenbergen *et al*. 2013) (Engel *et al*. 2014) (Dutch Government 2014) (Weieriks and Vlaanderen 2015)	(COAG 2011) (State of Queensland 2011) (NEMC 2012) (AGD 2012*a*) (AGD 2012*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (Queensland Government 2014*b*) (Queensland Government 2014*c*) (Queensland Government 2014*d*) (State of Victoria 2014*a*) (Productivity commission 2014*b*) (State of Victoria 2015)	(DHS 2011) (NRC 2012*a*) (NRC 2012*b*)	(UNISDR 2012*a*) (GFDRR 2012) (UN 2012) (IPCC 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNISDR 2015*a*) (O'Connell *et al*. 2015) (ADB 2015)
Evacuation planning, infrastructure and supplies	(Cheng 2006) (CMPG 2012) (Jiang *et al*. 2013)	(Vis *et al*. 2003) (de Bruijn 2004*b*) (Klijn *et al*. 2004) (NEAA 2011) (Engel *et al*. 2014) (Dutch Government 2014)	(DOTARS 2004) (State of Queensland 2010) (QRA 2011*b*) (AGD 2012*b*) (QRA 2012*a*) (AGD 2013) (Queensland Government 2014*c*) (Productivity commission 2014*b*)	(DHS 2011) (NRC 2012*a*) (NRC 2012*b*) (FEMA 2015*b*)	(UNISDR 2005) (UNISDR 2012*a*) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*)
Planning for/preventing disaster-related epidemics	(Cheng 2006)	0	(Queensland Government 2014*b*)	(DHS 2011) (NRC 2012*a*)	(IPCC 2012) (UNISDR 2015*c*) (Jha *et al*. 2012)
Recovery planning	(Cheng 2006)	(Zevenbergen *et al*. 2013)	(AGD 2009) (COAG 2011) (QRA 2011*b*) (QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2012*b*)	(DHS 2011) (NRC 2012*a*) (NRC 2012*b*) (DHS 2013) (CNY 2013)	(UNISDR 2012*a*) (GFDRR 2012) (UN 2012) (GoJ and WB 2012)

			(AGD 2013) (DAE 2014) (Queensland Government 2014*b*) (State of Victoria 2015)		(Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (UNISDR 2015*a*) (UNISDR 2015*c*)
Anticipatory transformational recovery planning; windows of opportunity	0	(NEAA 2009) (Zevenbergen *et al*. 2013) (Weieriks and Vlaanderen 2015)	0	0	(IPCC 2012) (UNISDR 2005) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (O'Connell *et al*. 2015)
RESPOND					
Information and communication systems, strategies	(CMPG 2012)	(Engel *et al*. 2014) (Dutch Government 2014)	(COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (AGD 2012*a*) (State of Victoria 2012*a*) (AGD 2012*b*) (AGD 2013) (Queensland Government 2014*b*) (DAE 2014) (State of Victoria 2015)	(DHS 2011) (NRC 2012*a*) (NRC 2012*b*) (DHS 2013) (White House 2013*c*) (CNY 2013)	(UNISDR 2005) (UNFCCC 2009) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNISDR 2015*c*)
Response capacity, capability and flexibility (local and scaled-up; staff; equipment; emergency supplies; skills; shelters; operation centres; interoperability and redundancy)	(CMPG 2012)	(de Bruijn 2004*b*) (Engel *et al*. 2014)	(COAG 2009) (Australian Government 2010*b*) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (AGD 2012*a*) (AGD 2012*b*) (State of Victoria 2012*a*) (State of Victoria 2013*a*) (Queensland Government 2014*b*) (Queensland Government 2014*c*)	(White House 2011) (DHS 2011) (NRC 2012*b*) (CNY 2013) (HSRTF 2013) (White House 2013*a*) (White House 2013*c*)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (ADB 2015)

			(Queensland Government 2014*d*) (State of Victoria 2014*a*) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014) (State of Victoria 2015)		
Drills and scenario simulations, training	(CMPG 2012)	(Dutch Government 2014)	(COAG 2011) (State of Queensland 2011) (AGD 2012*a*) (State of Victoria 2012*a*) (State of Victoria 2014*a*) (Barnes *et al*. 2014)	(White House 2011) (DHS 2011) (NRC 2012*b*) (DHS 2013) (CNY 2013)	(UNISDR 2005) (UNISDR 2012*a*) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (UNISDR 2015*a*) (UNISDR 2015*c*)
Decision support systems for response management	(CMPG 2012)	0	(Queensland Government 2014*b*) (DAE 2014)	(DHS 2011)	0
Volunteer recruitment, training and support	(CMPG 2012)	(Engel *et al*. 2014)	(DOTARS 2004) (COAG 2009) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (AGD 2012*b*) (State of Victoria 2012*a*) (COAG 2014) (Productivity commission 2014*b*) (DAE 2014) (Barnes *et al*. 2014) (State of Victoria 2015)		(UNISDR 2005) (UNISDR 2012*a*) (GoJ and WB 2012) (Jha *et al*. 2012) (IPCC 2014) (UNISDR 2015*c*)
RECOVER					
Financing recovery (e.g., insurance; maintaining insurance affordability /	(Cheng 2006) (CMPG 2012) (Jiang *et al*. 2013)	(Vis *et al*. 2003) (de Bruijn 2004*a*) (de Bruijn 2004*b*)	(DOTARS 2004) (DCC 2009) (COAG 2011) (QRA 2011*b*) (COAG 2012) (AGD 2012*a*) (AGD 2012*b*)	(NRC 2012*a*) (NRC 2012*b*) (White House 2013*b*) (CNY 2013) (HSRTF 2013) (GAO 2015)	(UNISDR 2005) (UNFCCC 2009) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012)

availability; charity; public relief and recovery funding; 'risk sharing' compensation; loans; subsidies; local labour; mitigation incentives)		(Dutch Government 2013) (Weieriks and Vlaanderen 2015)	(QRA 2012*a*) (State of Victoria 2012*a*) (AGD 2013) (State of Victoria 2013*a*) (DAE 2013) (Queensland Government 2014*b*) (Productivity commission 2014*b*) (Barnes *et al*. 2014)	(Thomas and DeWeese 2015)	(GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (ADB 2015)
Post-disaster needs assessment; local participation	0	0	(DOTARS 2004) (AGD 2009) (COAG 2011) (State of Victoria 2012*a*) (QRA 2011*b*) (AGD 2012*a*) (Queensland Government 2014*b*)	(DHS 2011) (DHS 2013) (CNY 2013) (HSRTF 2013) (White House 2013*b*) (White House 2014)	(UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (UNISDR 2015*a*)
RECOVER [subset: BOUNCE BACK TO PRE-EXISTING STANDARDS]					
Rapid rebuild to prior standards	(CMPG 2012)	(de Bruijn 2004*a*) (de Bruijn 2004*b*) (Mens *et al*. 2011) (Weieriks and Vlaanderen 2015)	(COAG 2011) (State of Victoria 2013*a*) (State of Victoria 2014*a*)	(White House 2011) (DHS 2011) (NRC 2012*b*)	(UNISDR 2012*a*) (GoJ and WB 2012) (Jha *et al*. 2012) (GFDRR 2014) (IPCC 2014) (UNEP 2014)
Non-financial recovery support (e.g., long term health; rebuilding communities)	0	0	(DOTARS 2004) (COAG 2011) (QRA 2011*b*) (State of Victoria 2012*a*) (State of Victoria 2013*a*) (DAE 2014)	(White House 2011) (DHS 2011) (NRC 2012*b*) (CNY 2013) (HSRTF 2013)	(UNISDR 2005) (IPCC 2012) (UNISDR 2012*a*) (Jha *et al*. 2012) (UNISDR 2015*a*) (UNISDR 2015*c*)
Recovery of existing industries	(CMPG 2012)	0	(COAG 2011) (QRA 2011*b*) (State of Victoria 2012*a*)	(White House 2011) (DHS 2011) (NRC 2012*b*) (CNY 2013) (HSRTF 2013)	(IPCC 2012) (UNISDR 2012*a*) (GFDRR 2014) (UNEP 2014) (WB and GFDRR 2013)

Ecosystem recovery	(Cai *et al*. 2011)	(Dutch Government 2009)	(State of Victoria 2012*a*) (QRA 2011*b*) (Queensland Government 2014*b*)	(White House 2011) (DHS 2011) (NRC 2012*b*) (CNY 2013) (HSRTF 2013) (USACE 2013)	(UNISDR 2012*a*)
RECOVER [subset: INCREMENTAL IMPROVEMENT]					
Improved rebuild or post-disaster upgrade	(CMPG 2012)	(de Bruijn 2004*a*) (de Bruijn 2004*b*) (Mens *et al*. 2011) (Engel *et al*. 2014)	(DOTARS 2004) (AGD 2009) (COAG 2011) (State of Queensland 2011) (QRA 2011*b*) (AGD 2012*a*) (Queensland Government 2014*b*) (Productivity commission 2014*b*) (Barnes *et al*. 2014)	(IPET 2009) (White House 2010) (DHS 2011) (NRC, 2012*a*) (NRC 2012*b*) (White House 2013*b*) (DHS 2013) (CNY 2013) (HSRTF 2013) (Thomas and DeWeese 2015) (GAO 2015)	(UNISDR 2005) (UNISDR 2012*a*) (GFDRR 2012) (IPCC 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*)
Adjustment of existing industries; diversification‡	(Liao 2012)	0	(QRA 2011*b*) (State of Victoria 2013*a*) (Queensland Government 2014*b*)	(DHS 2011) (NRC 2012*b*)	(UNISDR 2005) (UNISDR 2012*a*) (IPCC 2012) (GEF 2012) (GoJ and WB 2012) (Jha *et al*. 2012) (WB and GFDRR 2013) (IPCC 2014) (UNISDR 2015*a*) (O'Connell *et al*. 2015) (ADB 2015)
RECOVER [subset: TRANSFORMATIONAL CHANGE]					
Relocation; land use change (as part of recovery)‡	(CMPG 2012)	0	(COAG 2011) (QRA 2011*b*) (AGD 2013) (Queensland Government 2014*b*)	(CPRA 2012) (HSRTF 2013) (Thomas and DeWeese 2015) (GAO 2015)	(IPCC 2012) (Jha *et al*. 2012) (IPCC 2014) (UNEP 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (O'Connell *et al*. 2015)

New, flood compatible industries; alternative livelihoods‡	0	0	0	0	(GEF 2012) (O'Connell *et al*. 2015)
Recovery targeting long term improvements for the most vulnerable	0	0	0	(CNY 2013) (HSRTF 2013) (Thomas and DeWeese 2015)	(GFDRR 2012) (IPCC 2012) (UNISDR 2012*a*) (Jha *et al*. 2012) (WB and GFDRR 2013) (GFDRR 2014) (IPCC 2014) (UNISDR 2015*a*) (UNISDR 2015*c*) (O'Connell *et al*. 2015)

† , ‡ See footnotes for table S.7.2.

Supplement 3: Interpretations of resilience: narrative

1. China

References to disaster resilience in China are rare in both government and academic flood literature. Given the word's Latin origin it is unlikely to hold the same political resonance and power in Chinese as it does in English[52].

There is little consistency among Chinese academics about the interpretation of resilience in the context of Chinese flood policy. Gao *et al*. (2014) equate resilience to resistance strategies, such as sea walls and the financial capacity to build them. Structural measures also feature strongly in a discussion of resilience in Shanghai (Lu and Lewis 2015). Others link resilience to European 'room for the river' style approaches and 'soft' management measures (Cheng 2006; Huang *et al*. 2013; Jiang *et al*. 2013). This interpretation has been influenced by China's catastrophic 1998 floods in which key dykes failed. Post-disaster policies reveal a paradigm shift towards 'harmonious coexistence of man and nature' (Ma *et al.* 2010) which has resulted in a move away from structural control, towards damage reduction and flood management (Cheng 2006; Ma *et al*. 2010). This approach favours measures such as resettlement out of high risk areas, improved warning systems and evacuation. By contrast, Xiao *et al*. (2014), take a broad, societal view of resilience, examining how factors such as population growth, agricultural capacity, climate variation and culture affect the availability of adaptive options, with unresolved drivers gradually restricting options (and resilience) over time.

The word 'resilience' is not used in English translations of Chinese flood or climate policy documents, nor related research institution reports (Zhang and Wen 2001; CCICED 2004; P.R.C. 2007; P.R.C. 2012; P.R.C. 2015*b*). However, China participates in international resilience initiatives including the UNISDR's *Making Cities Resilient Campaign* (UNISDR 2012*b*; CAS 2014; Smith 2014). As part of this involvement, Chengdu pursued resilient development following the 2008 Wenchuan earthquake and is currently a role model for UNISDR's resilient cities campaign (CMPG 2012; UNISDR 2015*b*). Interestingly, the municipality's submission never uses the word 'resilience'. Prominent among Chengdu's strategies have been the rapid rebuild and reinforcement of roughly 635,000 buildings and associated infrastructure; financial subsidies;

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[52] Interestingly however, there is a Chinese story very similar to Aesop's 'Oak and Reed' tale in the *Tao de Ching* (chapter 76), including the words: "The gentle and yielding is the disciple of life…..A tree that is unbending is easily broken." (Lao Tsu, translated by Feng and English, 1973). In Taoism, water is Yin, the yielding female principle and it is viewed as being more powerful than Yang, the male principle; gender and flood control could form its own interesting study. The similarity of the Chinese and European tales (and their durability) suggests they have universal appeal and could be a culturally relevant way of equating the word 'resilience' with 'living with floods' or flood accommodation and distancing it from resistance options in the non-academic domain.

disaster forecasting, risk assessment and early warning; awareness raising; and response capability improvements. Primary responsibilities have been devolved to the local level and to residents. In terms of prevention, hazard areas have been designated, 4,000 households were relocated and infrastructure such as dykes and reservoirs have been built and reinforced. While physical reconstruction was rapid, some suggest it may not lead to long term resilience, and issues of rebuild quality and insufficient investment in rebuilding economies and communities have been raised (Olshansky 2013; Smith 2014). Nevertheless, Chinese interpretations of resilience incorporate the quality of 'rebound', shared information and shared responsibility.

2. The Netherlands

Dutch interpretations of disaster resilience are not static and mirror contemporary flood management policy. While initially, both academics and (the few) government documents that used the term 'resilience' associated it almost exclusively with novel 'room for the river' strategies, the range of measures currently linked with resilience now encompasses traditional structural measures as well.

Traditional dyke strengthening was able to cope with small floods. However, a series of near-miss flood events in the 1990s revealed this to be inadequate for large-scale disasters and future climate scenarios. In the early 2000s, resilience was used by Dutch academics to describe innovative methods of providing more room for rivers through relocation of dykes inland, the development of new floodways ('green rivers') and better structuring (compartmentalising) of existing polders. Instead of preventing floods, these measures aim to reduce flood peaks and enable gradual flooding of least valuable areas first. They also require significant transformation in terms of spatial planning, flood-compatible land use and buildings. This view of resilience, which sits within the pre-existing structural landscape of Dutch flood management, distinguishes 'resistance' strategies, such as dyke strengthening from 'resilience' strategies that aim to increase flexibility and buffers into the system (Vis et al. 2003; de Bruijn 2004*b*; Klijn et al. 2004; Smits et al. 2006; Wolsink 2006).

These early conceptions about resilience have since been reassessed by some of these same academics who now prefer the term 'robustness'. Robustness incorporates both resistance and the degree to which the hazard, once it overcomes the resistance threshold, can be made gradual through improved system design (Mens et al. 2011; Mens et al. 2015). Others in the academic community (e.g., van Slobbe et al. 2013; Engel et al. 2014) continue to view 'hard engineering' as an impediment to achieving resilience. Engel et al., for example, criticise new embankments built along the River Maas, concluding:

> our findings suggest that these changes could transform two self sufficient, responsible and resilient communities into two dependent, less prepared and therefore more vulnerable communities
>
> (Engel *et al*. 2014: 880)

The term 'resilience' has taken time to enter into (English translations of) Dutch government policies, and is absent from many key documents, including flood terminology documents; the influential Deltacommissie report; national spatial planning policy; water development plans; and many room for the river program documents (Dutch Government 2006; Deltacommissie 2008; Dutch Government 2008; Dutch Government 2011; Dutch Government 2015).

Despite its absence from these documents, it is clear that the Dutch government associates room for the river flood policies with resilience, including initiatives to set back dykes and broaden the river at Nijmegen (Dutch Government 2012; Nijssen 2012), and the current National Water Plan which describes climate change policies that increase space for rivers as 'resilience' (Dutch Government 2009). Resilience is strongly linked to spatial planning by both Dutch theoreticians and government agencies (e.g. NEAA 2009; Dutch Government 2014; Weieriks and Vlaanderen 2015).

While policy documents do not offer a definition of 'resilience', work published by government officials suggests that the 2009 UNISDR definition has been adopted (Weieriks and Vlaanderen 2015). This definition incorporates the word 'resist', under which structural mitigation such as dykes fit. This may explain the more recent association of dyke strengthening with resilience, for example, in Delta Programme documents.

The current Delta Programme emerged from the Deltacommissie's report (2008) and is described as a resilience strategy (Dutch Government 2013; Zevenbergen et al. 2013), although annual Delta Programme documents offer little identification of the overall program with the term 'resilience' until 2014 (Dutch Government 2014). The Delta Programme is broad and covers resistance measures, such as further reinforcement of dykes in heavily populated areas, as well as room for the river style measures and preparedness in more rural areas. The correlation of resilience with resistance also appears in other recent government documents. For example, a report prepared by PBL Netherlands Environmental Assessment Agency associates resilience with 'unbreachable dykes', designed not to fail if overtopped and deems flood-resilient construction unnecessary in such areas:

> the consequences of flooding are always less damaging when areas are protected by unbreachable dykes
>
> (NEAA 2011: 10)

However, unbreachable dykes can only provide protection only up to a limited height and could be viewed as an unrealistic long term goal by some, depending on the timeframe considered by policymakers (Rahmstorf 2010).

Measures associated with 'disaster resilience' in the Netherlands have thus evolved to reflect national policy. While initially relating almost exclusively to new 'living with floods' strategies, most recent Dutch policy documents also incorporate resistance measures.

3. USA

The USA has an all-encompassing view of disaster resilience, and it is linked to anticipatory measures, development controls, construction standards, ecosystem-based measures, preparedness, institutional reform, response capacity and rapid recovery. Resilience is almost universally associated with climate change *adaptation*, and some sources also describe climate change *mitigation* as a resilience measure to avoid future flooding.

Intriguingly, few references associate exposure reduction structures, such as levees, with resilience. This is likely to be due to recent major flood disasters characterised by failure of structural protection, such as the 1993 mid-west flood and 2005 flooding in New Orleans (Changnon 2000; Burby 2006; IPET 2009; NCLS 2009). Even where such measures are included in the suite of resilience measures, there is recognition that this type of measure can reduce risk awareness and increase flood consequences (NRC 2012*b*; FEMA 2015*b*). Reports into infrastructure and dam and levee safety equate resilience not with the structures themselves, but rather, with their redesign, improved management, maintenance, operation, legal enforcement, risk communication and similar measures (ASCE 2009; NRC 2012*a*; ASCE 2013). Similarly, a review into the 2005 New Orleans flooding attributed poor resilience to economic decisions, poor flood wall design and the lack of integration of flood defence systems and components (IPET 2009). Current New Orleans flood management strategies incorporate levees and flood walls, but such measures are described as 'protection' and are distinguished from 'resilience' measures, which are described in terms of enhancing ecosystem buffers, improved construction standards and buyouts (CPRA 2012).

While most USA documents examined do not link resilience to structural protection, a resilience plan prepared by the City of New York in the wake of Hurricane Sandy in 2012 is a notable exception (CNY 2013). Adamant that retreat from the coastline is not an option, the plan projects that climate change will extend the current 100-year floodplain from 11% of the city's area to 24% by 2050. The city has encouraged new waterfront investment and anticipates that the majority of population growth will occur in areas most at risk. In this context, the plan equates structural protection (to the 1 in 100 AEP level) to resilience. The plan does not project sea level rises beyond 2050, nor consider the adequacy of current development growth and structural protection strategies beyond this date.

Published just two months after New York's resilience plan, a report by the Hurricane Sandy Rebuilding Task Force references flood walls only to say they breached during the disaster. However, it strongly promotes ecosystem based approaches and investing in improved rebuild standards (HSRTF 2013). Taskforce findings have been influential in guiding federal climate and flood policy (White House 2013*b*; FEMA 2015*a*). While recognition of structural measures continues, the emphasis of federal flood risk policy is on a higher standard of risk avoidance and use of ecosystems-based approaches (FEMA 2015*a*; FEMA 2015*b*).

Resilience in the USA is also strongly associated with *preparedness*. This includes public awareness of risks, preparing disaster plans, continuity of critical infrastructure and services and institutional reform to improve mitigation incentives and program delivery. Preparedness activities aim to reduce damages through better planning, management and behaviour change. However, Richards (2010) notes that 'all plans work before the disaster' and preparedness activities may provide a false sense of security. The 2005 New Orleans disaster occurred shortly after the city had successfully completed a disaster planning exercise on 'Hurricane Pam', a theoretical storm more severe than Hurricane Katrina (Richards 2010). More concerning is the observation that by improving *perceptions* of safety, through well-intentioned emergency planning or levee building, governments also satisfy political objectives of maintaining land values and economic development in hazardous areas (Burby 2006; Richards 2010).

Shared responsibility and the need for partnerships are highlighted in some sources. This is particularly pertinent because, as a federation, the US Federal Government has limited power over some issues that are seen as key to improving resilience, such as land use planning, construction standards and their enforcement. Institutional incentives, including conditional federal funding, are recommended (NRC 2012*b*) and adopted (Wright 2000; White House 2015*a*) to help achieve these results. As many critical infrastructure assets are in the private domain, public-private partnerships are viewed as a priority to ensure business continuity in the event of disaster.

4. Australia

In Australia, the concept of disaster resilience was first used extensively in an influential report to government on disaster mitigation first written in 2002 (DOTARS 2004). The report's interpretation of resilience remains current, and includes a risk management approach based on hazard information and risk assessment; the concept of local communities sharing responsibility for risk management; preparedness; capacity building; and the continuity of critical infrastructure and services. Critically, the focus is on disaster mitigation, an emphasis that continues in more recent documents.

Through the National Strategy for Disaster Resilience (COAG 2011), resilience is now central to Australian disaster management, and is the basis of competitive grants programs and state government policies. The strategy is broad and offers no disaster-specific measures (such as fuel reduction or efficient drainage). Instead it stresses the importance of preparedness and capacity building. For the physical environment, the strategy advises land use planning, construction standards and broaches the inadvisability of rebuilding in hazardous areas following an event.

Improved development planning is a common theme in Australian resilience documents. However, competing development needs often result in limited development control of floodplains (Wenger 2013; 2015*a*). Theoretically, accurate understanding of risks leads to improved decision making and to this end, Australia's National Partnership Agreement on Natural Disaster Resilience has had a strong focus on generating hazard information. However, understanding of risks is no guarantee of good planning outcomes. In an example from Queensland, a 970-dwelling development was approved in an area so risky that approval conditions required an evacuation helipad, lifeboats and three days' food supply (Productivity Commission 2014*b*). While local governments are primarily responsible for land use planning and risk management (AGD 2012*a*), development legislation is a State Government responsibility. Approval in this case was attributed to lack of immunity from legal challenges, suggesting that state institutional arrangements do not always support development control rhetoric; 'shared responsibility' devolves and absolves higher levels of government.

Australian documents suggest a stronger linkage of resilience with structural mitigation than other countries. Moreover, some of that association is obscured under the general term 'mitigation'. For example, the Queensland's Resilience Strategy (Queensland Government 2014*b*) links resilience with the implementation of specified programs. Some include preparedness but others are exclusively structural in focus (e.g., levee building and raised roads with flood resistant surfaces), with measures such as house raising and property buyback ineligible (Queensland Government 2013*a*; Queensland Government 2015). Similarly, Victoria's disaster management policies refer to mitigation (State of Victoria 2012*a*; State of Victoria 2015) and its resilience programs offer evidence of support for both structural and preparedness measures. However, there is no evidence of state-supported house raising or relocation activities (State of Victoria 2014*a*; State of Victoria 2014*c*). In part, this can be attributed to perceptions about private benefits (BTRE 2002).

Perhaps least linked with resilience are the ecosystem based measures. Where this is covered, it sometimes seemed tokenistic. Measures such as wetland protection may only merit one line in a table (Productivity Commission 2014, Volume 2, p.374) while whole sections or chapters are devoted to measures such as betterment and levees. However, the retention of existing floodplain functions, such as flood conveyance and storage are supported in floodplain management and development planning documents (QRA 2012*b*; AGD 2013; Queensland Government 2014*d*; State of Victoria 2014*b*).

The importance of improved rebuild following disasters is linked to resilience in key sources but many highlight that achieving this objective is impeded by ineffective administrative arrangements (DOTARS 2004; QRA 2011*b*; Productivity Commission 2014*b*). A similar situation occurred in the USA when it first implemented improved rebuild policies, which led to improved administrative and budgetary support (Wright 2000, pages 69, 78). Following consecutive floods in Queensland, political pressure has increased and reforms to disaster financing are currently under discussion (Productivity Commission 2014*b*).

5. International bodies

Resilience is a primary objective in international organisations, crossing the policy spheres of climate adaptation, sustainability, economic development and disaster risk reduction. The Hyogo Framework for Action (HFA) has been especially influential in defining and promoting disaster resilience internationally.

The HFA has recently been replaced by the Sendai Framework (SF). The SF reduces the prominence of the term resilience and 'disaster risk reduction' takes centre stage instead. In some parts of the document, preventing and reducing disaster risk are said to strengthen resilience (e.g., paragraphs 5, 17; priority 3); in others, reducing disaster risk and building resilience appear more weakly linked (e.g., priorities 1, 2 and 4).

Global case study documents tend to exhibit a high level of support for a wide range of measures. Guided by the HFA, documents strongly associate resilience with all measures believed to contribute to disaster risk reduction, including improved development and construction controls, resistance measures, ecosystem based measures, disaster warnings and preparedness. Sources also recognise that many developing countries have low response capacity, and this is incorporated. The global case study thus reflects the need to be inclusive on the international stage to accommodate the varying needs and approaches of all countries.

Addressing underlying social vulnerabilities to disasters is a dominant theme of international documents. International resilience documents explore this in great detail and argue that addressing it is fundamental to achieving societal resilience to disasters, climate threats and other stressors (e.g. Jha *et al*. 2012; UNISDR 2015*a*). This is the most significant difference in emphasis compared with the other case studies examined, and is consistent with the aim to address underlying vulnerabilities as part of the international development agenda.

Of the other case studies, the USA is most closely reflects the awareness of social vulnerability in global case study, perhaps due to evidence that the socially disadvantaged were disproportionately affected by Hurricane Katrina floods (Kates *et al*. 2006; Tierney 2006). Sources from the Netherlands rarely cover disadvantaged groups. Those that do either discuss it in the context of overseas policy (Weieriks and Vlaanderen 2015) or deny that inequity (based on access to information, resources and health) is an issue in the Netherlands (de Bruijn 2004*b*). However, (Wolsink 2006) makes it clear that there are power inequities in the Dutch development system. Addressing underlying social issues is also muted in Australian sources. The 2012 Queensland Floods Commission of Inquiry revealed that planning controls for affordable housing were weaker and that vulnerable people (such as those in aged care) were housed in risky areas (QFCI 2012; Wenger 2013). However, resilience strategies that address underlying vulnerability tend to promote targeted information dissemination and do not display an understanding of these deeper, systemic issues. This is also reflected in Australian vulnerability assessments which are more likely to be mentioned in the context of infrastructure than social groups. To some extent underlying social disadvantage is an intractable problem, dictated by right wing – left wing politics. It is easily promoted on the international stage but may be harder to implement nationally.

Thesis Conclusion

1. Introduction

This section answers research questions posed in the introduction and synthesises thesis findings. It identifies the research contribution of the thesis and proposes areas for further research.

The research aim was to identify the most adaptive (and least adaptive) options for addressing climate change related flooding. It also addressed the practical aspects of how easy it would be for Australian governments to adopt adaptive approaches and whether current disaster resilience policies are likely to achieve adaptive outcomes. To this end, the following research questions were asked:

1. *Which approaches to flood management are most likely to maximise the capacity to deal with anticipated changes in climate and population?*
    a. *Are innovative approaches that appear to be adaptive overseas transferrable to Australia?*
    b. *What barriers need to be overcome and which reforms would be necessary to implement measures and approaches with the greatest adaptive potential?*
2. *Is the current 'resilience' paradigm, popular in many parts of the world, adequate to address future flood threats?*
    a. *What are its strengths and weaknesses?*
    b. *If it needs to be replaced, what does it need to be replaced by?*

Research began with an investigation of Australian and overseas flood reviews to determine different approaches to flooding, their advantages and disadvantages. This work formed the basis of comparative case studies used throughout the work. Analysis drew on a number of theoretical concepts, including characterisations of adaptation and maladaptation, comparative public policy, institutional theory and the concept of resilience as applied to disaster management. This resulted in seven papers submitted for publication over the course of the PhD, in compliance with the Australian National University's policy on PhD by compilation.

2. Research findings and discussion

Publications 1-7 explored various themes relating to research questions. Research contributions and the new knowledge generated by publications are summarised in Table 8.1. Findings from some of these publications have been referenced by organisations involved in post-flood debates about appropriate management measures and funding, including the Australian

Business Roundtable for Disaster Resilience and Safer Communities (DAE 2013) and the Productivity Commission report into Natural Disaster Funding Arrangements (Productivity Commission 2014*b*).

Table 8.1: Research contribution of thesis publications.

Publication and research focus	**Research contribution (research question addressed: Q1; 1*a*; 1*b*; 2; 2*a*; 2*b*)**
Publication 1 Living with floods: key lessons from four Australian flood reviews and similar reviews from the Netherlands, China and the USA (Wenger *et al.* 2013) Research compared approaches to flood management in four countries. Strategies were assessed against adaptation criteria (see also Appendix 4 of the thesis).	1. In contrast to other case study countries, Australian flood reviews failed to address future threats, limiting debate about whether current management approaches will be adequate. **[Q1]** 2. Significant deficiencies were identified in Australia's flood information and warning coverage, and its development legislation and processes, including reliance on the 1 in 100 AEP standard for development planning. **[Q1]** 3. All case studies (including Australia) have documented problems with structural approaches. While not a new finding, its recurrence exposes an intractable problem that needs addressing. **[Q1]** 4. Alternative ecosystem-based measures are used overseas and are best characterised as adaptive, but this is a neglected area in Australian flood management. **[Q1]** 5. Compared with overseas, other shortcomings of Australian flood management include the lack of a systematic approach to relocation (despite national strategy) and customary lack of investment in preventative recovery (betterment). **[Q1]**
Publication 2 Living with floods: Key lessons from Australia and abroad [an extract] (Wenger et al. 2013) Research investigated adaptive strategies developed by the Netherlands to prepare for future flood risk: explores focus, innovations, scope, processes and reasons for success.	6. Structural measures have limits. Consequences of failure mount as dykes are augmented and maintenance and running costs increase. Other strategies are needed to address climate change threats. **[Q1]** 7. The Netherlands focuses on prevention/mitigation, works with ecosystem processes, has an extended and indefinite planning timeframe supported by legislation and funding arrangements, has an inter-sectoral approach, seeking opportunities and win-win solutions and compatibility with broad societal goals. **[Q1]**
Publication 3 Climate change adaptation and floods: Australia’s institutional arrangements (Wenger 2013) Research into institutional arrangements for flood management at the time of 2010-11 floods.	8. Australia's institutional arrangements for flooding at the time of the 2010-11 floods are likely to have contributed to the scale of the disaster, including development planning loopholes and inadequate funding for flood information, warning systems and prevention / mitigation. **[Q1*b*]** 9. Australia's constitution and non-interventionist approach mean that while high level documents express the need to integrate climate change into disaster management, rhetoric tends to be aspirational rather than mandatory. **[Q1*b*]** 10. Policy conflict is a key issue, especially between short term development interests, affordable housing objectives and long term community safety and damage costs. **[Q1*b*]**

Publication and research focus	Research contribution (research question addressed: Q1; 1*a*; 1*b*; 2; 2*a*; 2*b*)
	11. There is a lack of accountability for irresponsible development decision making. Risk takers (developers and sub-national government levels) are different to risk bearers (residents, national government, taxpayers). **[Q1*b*]** 12. Inadequate state legislation means local governments are subject to expensive legal challenges if they decide not to approve inappropriate development applications. **[Q1*b*]** 13. There are barriers to ecosystems based approaches, including flood studies based on municipal rather than catchment boundaries and catchment agencies that lack legal authority in the development process. Another barrier is lack of public understanding about flood causes. **[Q1*b*]** 14. Australia's approach to managing floods, and the ability of the landscape to store and retain water, have implications for how well it will cope with increasingly severe droughts due to climate change. **[Q1]**
Publication 4 Sink or Swim: alternative approaches to flood disaster reconstruction and mitigation (Wenger 2014) Research into the potential for policy transfer of adaptive approaches.	15. Countries have different underlying incentives and governance structures, greatly complicating policy transfer. **[Q1*a*]** 16. Relocation (more broadly defined as land use change) is closely linked to ecosystems based approaches. **[Q1]** 17. Analysis of program documents suggests decreasing support for relocation and house raising in Australia. **[Q1*a*]** 18. Using Australian and overseas examples, factors that facilitate relocation and improved standards of rebuild were identified. **[Q1*a*]**
Publication 5 Better use and management of levees: reducing flood risk in a changing climate (Wenger 2015) Research into the future directions of flood management in case study countries and the place of levees.	19. Drawing on case study findings, levees were assessed against both adaptive and maladaptive criteria and were found to be best characterised as maladaptive. **[Q1]** 20. Ways in which levee use and management can be improved were identified, including better incorporation of external costs. **[Q1*b*]** 21. Identifies institutional reasons for the Australian 'levee love affair' (Tobin 1995) and factors that have allowed other countries to incorporate more adaptive options. Institutional factors include problem recognition, program delivery, financial incentives and decision making tools and timeframes. **[Q1*a*]** 22. Resilience policies support the Australian Government’s non-interventionist approach to flood management. **[Q2*a*]**
Publication 6 Building walls around flood problems: the place of levees in Australian flood management (Wenger 2015) Research into Australia's levee performance and reliability, administrative	23. Basic information about urban and rural levees and levee-like structures, their location and maintenance status, is not collected by all states / local governments and this is a serious problem for levee management. Where collected, it is not always publically available. **[Q1*b*]** 24. To date Australian urban levees have generally been reliable and most withstood floods between 2010-13. **[Q1]** 25. Recent Australian examples of international levee problems, including the facilitation of development in high flood risk areas; reduced incentives to mitigate; loss of flood awareness, ongoing

Publication and research focus	Research contribution (research question addressed: Q1; 1*a*; 1*b*; 2; 2*a*; 2*b*)
and regulatory arrangements.	maintenance costs; prolonged flooding and delayed recovery due to impeded drainage. **[Q1]** 26. Rural levees cause extensive damage to Australia's riparian ecosystems. Levee maintenance also compromises riparian health **[Q1]** 27. Devolution of flood management to local government limits assessment of broader catchment impacts. Assessment may stop at town boundaries, may be subject to moving baselines and generally fails to account for cumulative effects. **[Q1]** 28. The trend is towards stronger levee regulation to reduce levee problems and to ensure maintenance / reliability. **[Q1*b*]** 29. Availability of flood risk information is central to Australian resilience policy but fails to prevent the development of high risk areas. **[Q2*a*]** 30. State development legislation fails to adequately accommodate future climate change; nor does it support local governments that wish to do so. This is likely to fuel future demand for levee protection. **[Q1*b*]**
Publication 7 The oak or the reed: how resilience theories are translated into disaster policies (Wenger, under review) Explores disaster resilience interpretations using five case studies.	31. The PPRR framework was modified to make it easier to distinguish adaptive and maladaptive flood management options. **[Q1]** 32. Resilience theories support variable resilience interpretations. Of the five case studies, the Netherlands appeared to have the most adaptive interpretation of disaster resilience and Australia the least. **[Q2]** 33. Disaster resilience policies do not necessarily support long term adaptive outcomes. Especially in Australia and the USA, the emphasis is on maintaining the status quo, albeit with incremental change. **[Q2*a*]** 34. SES resilience theory highlights relationships between system elements. Intervention points can be identified to move to more desirable resilience regimes (transformation). **[Q2*a*]** 35. Levees could be used to facilitate transition to flood compatible land use using time limited approvals, pre-planned decommission and temporary development moratoriums. **[Q1]** 36. The concept of resilience is fertile ground for theorists but (except politically) has been less useful for emergency managers. Long term adaptive outcomes need to be the focus. **[Q2*b*]**

2.1 Which flood management approaches have most adaptive potential?

Based on case studies, this thesis presented different approaches to flood management and assessed them to establish which have the most adaptive potential to address climate change risks. Using adaptive and maladaptive criteria (**publication 1; appendix 4** and **publication 5**), structural measures were found to be least adaptive. Measures such as levees are built to cope with a flood of a defined magnitude which, given loss of climate stationarity, will become increasingly unreliable. There is also abundant evidence of negative externalities, path dependency; and loss of flood experience that worsens the impacts of large floods.

Overseas case studies have been particularly helpful in illustrating the long-term geomorphological effect of structural measures such as levees. Sediment starvation and desiccation are common problems for levee-protected areas, while additional sediment deposition of the reduced floodplain area between levee banks further reduces flood storage capacity. Desiccation can compound problems and in the Netherlands has caused the decomposition of peat soils. In the USA, sediment starvation of saltmarsh has reduced natural flood protection for New Orleans. In China, some rivers are now several metres higher than levee-protected areas of the floodplain due to sedimentation changes, increasing the vulnerability of inhabitants. Such changes take centuries to manifest and are associated with the degradation of riparian ecosystems and resources on which human economies and well-being depend. Commonly used decision-making tools, such as cost benefit analysis, use a discount rate of 20-30 years, which seems inadequate for assessing such long-term adverse impacts. Use of levees also creates path dependency, whereby 'protection' encourages additional development and increases potential damages. This is the case for other types of structural mitigation such as dams, the Wivenhoe Dam being a recent Australian example.

Non-structural and ecosystem-based measures appear most adaptive as they are generally flexible, reversible, and have co-benefits. In this respect, the highest priority for adaptive flood management is development planning to ensure that land use in floodable areas (taking account of longer term future risks) is flood compatible. Once 'planned' development becomes 'existing' development options narrow. Investment in structural mitigation, risk awareness and preparedness campaigns and emergency response and recovery are symptoms of planning failure. Reversing past land use decisions through relocation is hard to achieve (as seen in **publication 4**) and it is far better to prevent inappropriate development from happening in the first place.

In **publication 2**, the Netherlands provides a case study of an adaptive approach to flood management. Features include a long term planning horizon, supported by long term program implementation and funding arrangements; increasing the area of floodable land through measures such as levee setback and relocation; flood compatible land use and building design; integrated water resource management to achieve joint funding and multiple win-win solutions for sectors and local communities; and a long-term approach to development approvals to ensure decisions made now do not compromise future flexibility. Another advantage of the Dutch 'retain-store-drain' approach is that it replenishes groundwater tables and forms a barrier to saltwater intrusion. This is useful for addressing related climate change issues of increased drought and rising sea levels.

2.2 Barriers to policy transfer

Rose (2005) argues that successful policy transfer relies on a clear understanding of the program context in both 'donor' and 'receiver' countries. The institutional context that allowed existing flood management policies to develop in the first place is likely to be supported by laws, funding and vested interests that are resistant to change. Change is therefore unlikely where nothing is apparently wrong with existing programs: *problem recognition* is needed to overcome inertia, which often occurs when a disasters reveal policy inadequacies. **Publication 3** examines the institutional context in Australia, including roles and responsibilities of different levels of government, laws, policies, funding arrangements, information, development planning provisions and market mechanisms. This is developed further in **publication 5**, which looks at key policy transfer issues.

Publication 5 extended the Netherlands case study (**publication 2**) to investigate the program delivery arrangements of a program 'donor' country, with Australia as the program 'receiver'. Problem recognition, governance structures, decision making tools and other program delivery arrangements were found to influence the type of flood management option selected.

Problem recognition emerged as an issue for Australia. While rising damage costs were a common concern, unlike other countries, Australia generally failed to recognise the problems associated with using structural measures and their limitations when dealing with climate change. Furthermore, to date Australia has experienced no mass casualties due to levee failure as other countries have (**publication 6**). That Australian flood reviews failed to assess the adequacy of different measures to address climate change (**publication 1**) was a missed opportunity to raise awareness of problems and debate about suitability of current approaches. Institutional barriers identified in **publication 5** included:

- devolved responsibility is not compatible with a river basin approach;
- decision making processes are dominated by engineering firms (through flood study and options analysis processes);

- decision making tools have inappropriate short timeframes that may not adequately factor in the externalities of engineering options nor assess potential co-benefits of alternative options; and
- perverse financial incentives.

Perverse financial incentives were comprehensive, covering almost all players. They included external funding for structural measures (as opposed to privately funded property based measures); cheaper insurance premiums in levee protected areas; new land opened up for development; and penalties for local governments wishing to restrict development. Policy conflict that encourages the development of cheap, flood prone land is exacerbated by the responsibilities of different levels of government whereby funding for policy failure (flood damages) is externalised. The Federal Government has limited constitutional power to coerce responsible land management and appears unwilling go beyond exhortative-styled policy instruments (**publication 3**). The current institutional context of the 'program receiver' thus appears unfavourable for policy transfer.

Policy transfer was also covered in **publication 4**. As discussed, flood risk is likely to increase due to both sea level rise and more intense precipitation events. This means that ultimately, relocation may be the only alternative for some areas. Moreover, relocation is sometimes a prerequisite for ecosystem based approaches and flood compatible land use. Understanding the factors that make relocation successful is therefore important when investigating climate change options.

Publication 4 investigates relocation policy motivations and again finds subtle differences between countries in the problems countries aim to address. It also examines program delivery, such as implementation timeframes, perceptions of cost, funding arrangements and whether relocation is implemented as a pre-disaster risk management activity or a post-disaster recovery activity. It was found that underlying incentives and structures were very different. Superficially, the USA has a very similar federated state system, with states primarily responsible for flood management. However, through its National Flood Insurance Program, the US has more at stake. Flood damage is its second highest potential liability after social security. Unlike the Australian government, the US national government's flood insurance program makes the Federal Government responsible for *private* losses. The Government found it was paying up to seven times a property's value due to repeat damages. Arguably, it makes more sense to invest in relocation or house raising than to buy a property seven times over. Australian governments are not responsible for private losses but only for losses to public infrastructure. This means that investing in relocation and house raising only benefits private individuals, while levees, that protect many properties, can be labelled a public benefit. Underlying institutional structures such as who pays and who benefits is a big challenge for policy transfer. This was also reflected in differing incentives for effective flood prevention through development planning between different government levels.

2.3 Are adaptive approaches transferrable to Australia?

The starting point for policy transfer is for the policy donor and receiver to share a common problem. In the case of flood management, the most obvious common problem is escalating damage costs. Australia also shares common problems with structural approaches to flood management **(publication 6)** and has other climate related concerns such as reduced water availability (**publications 2, 3**). Rather than investing in measures like levees that appear maladaptive in the long term, policy transfer offers Australia the opportunity to a short cut and learn from the successes and failures of other countries. This thesis drew on institutional theory and comparative public policy to find out how easy it would be to transfer adaptive policy options to Australia.

Emergency management related policy transfer has occurred in the past, especially between the USA and Australia. However, transfer is not always complete. The PPRR framework (or 'comprehensive flood management') originated in the USA and transferred not only to Australia but all over the world (**introduction** and **publication 7**). However, despite the transfer of the framework as a categorisation of management options at different disaster phases, the transfer of its underlying intent was perhaps less successful. The US version of the policy aimed to increase investment in strategic prevention, mitigation and long term recovery and to integrate these into better resourced and organised operational prepare-response phases. Successive Australian reviews have illustrated the failure of Australia to sufficiently invest in mitigation and preventative recovery (DOTARS 2004; Productivity Commission 2014*b*). Arguably, Australia managed to transfer certain program elements but failed to transfer its ultimate objective.

In another example, Australia enthusiastically adopted the USA's actuarial standard, the 1 in 100 AEP flood, as a safety standard for development planning (**publication 3**). However, the standard was adopted in isolation from its donor program, the US National Flood Insurance Program. In the US, the 1 in 100 AEP flood was used as an actuarial standard for program implementation. The program intent was to ensure that landowners who chose to inhabit flood hazard areas paid the full costs of living there through insurance premiums, rather than costs being externalised to taxpayers. It also provided a lever for federal government to encourage development regulation (Wright 2000:34). Only an element of the US parent program was adopted by Australia and it was misinterpreted as a level of safety.

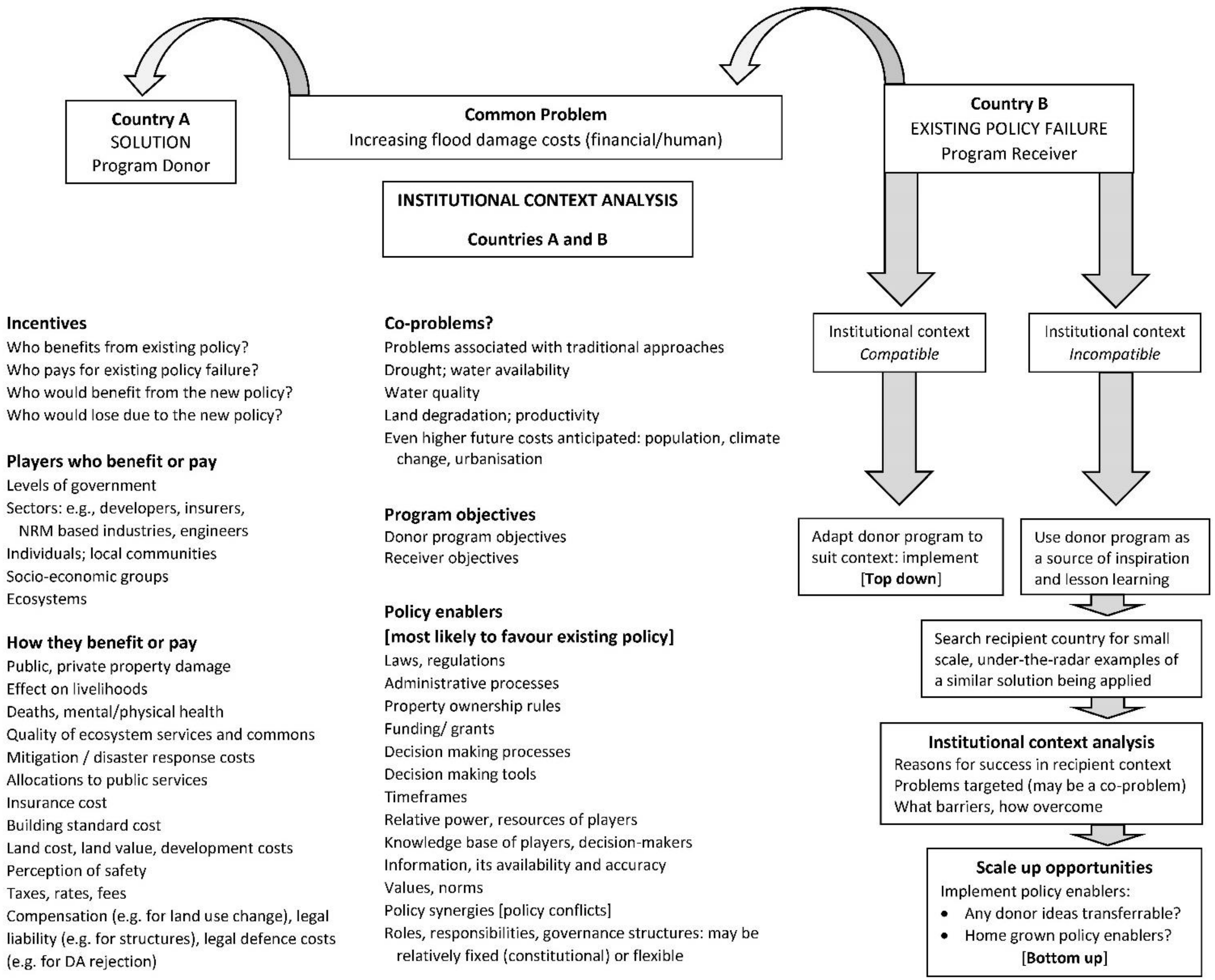
These examples demonstrate that transfer has taken place in the past but that little attention has been paid to program objectives. This is a concern as without this, transfer could be meaningless or counterproductive.

The next question is whether it is possible to transfer adaptive flood management options from overseas to Australia. Comparative public policy aims to save time and effort by transferring a successful *overseas* program to a new setting to solve common problems, the advantage being that the overseas program has been tried and proven. Although it seems logical, the findings of this thesis suggest that transfer of may be hard to achieve. Although overseas examples can identify solutions, institutional settings may be so different that this can greatly complicate transfer. In **publication 4**, for example, it was found that underlying incentives for relocation were vastly different between countries. **Publication 5** suggested that underlying systems and structures, such as which level of government was responsible for what, which can be constitutionally determined (and thus difficult to change), could also hamper transfer.

Despite these findings, comparative public policy is still a useful exercise. Overseas flood management programs can provide examples of innovative policy from which to gain inspiration and to identify adaptive alternatives. **Publication 4** illustrates that there is ample scope for lesson learning from overseas examples to improve program delivery.

Perhaps a more useful approach would be a hybrid one, whereby adaptive solutions to problems are identified using overseas examples (see Figure 8.1). This can be used as a starting point to identify cases of where similar strategies have worked (or not worked) in the context of the Australian political and institutional system. This may mean searching among low profile, small-scale local initiatives rather than high level national programs. What is it that makes these local initiatives succeed or fail. How do they compare with overseas examples. Did they encounter similar institutional barriers and how were these overcome in each country? Home grown Australian examples are likely to be more relevant to policy makers, implementers and decision makers instead of appearing remote and unrealistic. Proof, even on a small scale, that barriers can be overcome and similar strategies can succeed in Australia, provides evidence that solutions are locally applicable.

Figure 8.1: A hybrid policy transfer model for flood management



While there may be local examples, success may be determined by unique circumstances which could limit broader application. **Publication 4** showed that reasons for Grantham's relocation success included courageous leadership and a high media profile following disaster. Grantham's success was not able to be duplicated by communities seeking to follow Grantham's precedent (**publication 5**). Victoria's Lower Loddon relocation was a once-off opportunity to benefit from complementary irrigation efficiency funding and is not supported by ongoing flood recovery programs.

Australian ecosystems based examples have also been identified, including the Clarence Floodplain Project and a wetland restoration project at Leeton, both of which had multiple co-benefits (**publications 4, 5, 6 and appendix 4)**. Although a Moreton Bay sediment-control proposal covered in **publications 3 and 4** failed to achieve government support, the Queensland Government has recently purchased property to achieve sediment control in a different catchment (Willacy 2016).

Another local example of an ecosystem-based approach emerged too late to be included in a relevant thesis publication but it is worth discussing here as it illustrates the type of adaptive management covered in **publication 3** and the potential for further research into small scale Australian successes. In this example, trials were initiated by a farmer at his property near Bungendore in an upper catchment of NSW at the top of the Great Dividing Range. He was concerned that his land was degraded, had low productivity and was susceptible to drought. The property owner implemented measures to rehydrate the landscape, including a series of 'leaky weirs', revegetation to improve infiltration and improved grazing management. The leaky weirs retain water in the landscape and release it slowly. The creek, at one time regularly dry, now has running water the year round even during drought. Downstream water quality is now potable, native habitat has been restored and productivity has increased by 60%. The project has raised the interest and participation of other catchment farmers and is gaining international recognition for its success in sustainable agriculture (Peel, pers. comm.)[53]

There are some interesting points to note in this example. Firstly, the leaky weir structures are currently illegal works. In the Mulloon catchment, the government has allowed the weirs as a trial project –farmers outside the catchment who have emulated the techniques have been threatened with fines of $1 million (Thistleton 2015). Secondly, the primary motivation for the project was drought susceptibility, land degradation and low productivity, not flood damage. And yet the solutions implemented are precisely the type of management that is needed to

[53] Luke Peel, Research Coordinator, Mulloon Institute, 5; 7 September 2016.

reduce flood velocity, flood peaks and damages in more densely populated areas downstream; it is too late to slow the water once reaches the lower catchments (**publication 3**). In this example, flood mitigation is a co-benefit. This reveals the importance of examining co-problems when searching for in-country examples of solutions applied elsewhere. Where an innovative approach has been operationalised (perhaps for different reasons) within a country's own political context, it is likely to have greater influence and implementation potential than overseas examples.

2.4 Will disaster resilience strategies be adequate to address future flood threats?

Central to Australia's flood management programs is the concept of disaster resilience. The question of whether or not this facilitates long term adaptive outcomes was investigated in **publication 7**. It looked at the origins of different resilience interpretations and how this influences which type of flood management approaches and measures are used in different parts of the world. Using both quantitative and qualitative analysis, the paper used case studies to find out which activities were linked to resilience in different parts of the world. Perhaps unsurprisingly, it found that this varied according to country and that some appeared more adaptive than others.

Publication 7 findings suggest that the concept of disaster resilience has been enormously productive for theoretical research and that it has generated new ideas and ways of thinking about disasters. However, once it is used as the basis of policy, resilience definitions are too malleable. Any measure can be promoted politically as increasing resilience, whether or not it supports long-term adaptive outcomes. Moreover, disaster resilience tends to support the *status quo* which can hinder transformative adaptation.

Another contribution of **Publication 7** is its use of the Social-Ecological-Systems (SES) perspective of resilience to investigate intervention points for moving from a maladaptive, undesirable resilience régime to a more desirable one. Some authors have identified this as a priority for resilience research (Miller *et al*. 2010; Sjöstedt 2015). Matyas and Pelling (2015) suggest that a significant weakness of SES resilience theory is that it tends to fail when it comes to accounting for politics and when considering 'agency' and the behaviour of actors within a system. This seems surprising given that the root of SES resilience is embedded in the consideration of relationships between system elements. **Publication 7** demonstrates régime transition using the seemingly intractable 'levee paradox' as an example. This is an undesirable feedback loop that is characteristic of path dependency. **Publication 7** identifies intervention points and considers the institutions and motivations that have made this problem so difficult to overcome.

It also forms a satisfying conclusion to questions about the place of levees to adapt to climate change: such measures are best viewed as a temporary measure to aid transition.

2.5 Should disaster resilience be replaced as a concept to guide emergency management?

Publication 7 indicated that resilience will not necessarily lead to adaptive outcomes. The question to consider, therefore, is why resilience has been chosen to guide emergency management. If it is to maintain existing systems and structures, even if it means having to use maladaptive measures, then in the short term resilience strategies will succeed until costs become too high to support. On the other hand, if the ultimate aim of disaster management is to achieve long term adaptive outcomes, this needs to be made a more explicit goal and tools will need to be developed and implemented to support it.

Publication 7 proposes a revision of the traditional PPRR framework to make adaptive options more easy to distinguish. To this end it provides a prototype framework. It recommends the analysis of individual measures to understand under what circumstances they can be used to achieve adaptive outcomes. It also proposes that rather than 'resilience', the aim for emergency managers in a changing climate should be to negotiate long term adaptive pathways.

Emergency management agencies cannot achieve this objective alone. Responsible development planning is key to controlling future damage costs. Where development needs are 'balanced' against community safety objectives, policy failures are bound to happen and will compound at the expense of future generations. Perverse incentives in the Australian institutional setting that encourage the development of unsuitable areas need to be addressed. In many countries, safety standards are much higher than in Australia and even in the USA, where the 1 in 100 AEP level originated and was applied to development planning to implement its national flood insurance program, this level has been recognised as inadequate. Planning, at least for federal government assets, has been tightened to meet a new 1 in 500 AEP standard (FEMA 2015*a*; FEMA 2015*b*). This is a more adequate buffer for future climate uncertainty.

3. Future research and concluding remarks

This research aimed to determine whether Australia was on the right track to manage growing flood risk due to climate change and other threats. To do this it identified adaptive approaches, explored the potential for policy transfer and assessed the suitability of resilience theories to guide disaster policy into the future.

Having determined that the potential for policy transfer (defined as transfer between different countries) was limited, it was unable to fully explore home grown solutions. A small number of local examples were identified of ecosystem based approaches and relocation, along with reasons for their success or failure. However, the research carried out in this area suggests that more could be done to identify successful locally grown examples of solutions that have proved effective overseas.

Perhaps the greatest limitation of this research relates to policy conflict, in particular, between development planning, community safety and flood damage costs. Reasons for the conflict were explored, as were perverse incentives and potential reforms (**publication 3).** However, while Australia recognises inappropriate development is an issue, and that generous Commonwealth recovery arrangements limit sub-national accountability (Gibbs and Hill 2011; NEMC 2012; Productivity Commission 2014*b*), Australia seems a long way from resolving the situation. This is problematic given that improved development planning is a high priority for adaptation to flood risk. More work is needed to determine which solutions are most likely to be workable and politically palatable.

Work on resilience could also be extended. As discussed, a prototype framework was developed to better distinguish adaptive from maladaptive measures. However, the framework was constrained by the sources used and their level of detail. In particular, it was observed that while many sources linked development planning and construction standards to resilience, that planning intent often aimed at *maintaining* the ongoing development of hazardous areas as locations for high risk assets, rather than avoiding them. A revised framework would need to make the intent behind such activities clearer. Other revisions could further develop underlying causes, which formed a composite category in the prototype.

While **publication 7** makes findings about the application of resilience theories to disaster management and suggests that the ability to negotiate long-term adaptive pathways would be a better focus, research did not extend further than this. Identifying *how* to shift this focus was beyond the research scope. As its ambiguity is politically useful, abandoning the concept may be a challenge.

Even though drivers such as global warming and population growth are likely to see disaster costs continue to grow, this research shows that adaptive options are available that Australia could implement to minimise costs and maximise opportunities. The challenge remains the uptake of these options.

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Appendix 1: Publication format

The following pages show the first page of text reproduced in the thesis (and cover if applicable) in publication format.

Publication 1
Wenger, C, Hussey, K, Pittock, J, 2013, 'Living with floods: key lessons from four Australian flood reviews and similar reviews from the Netherlands, China and the USA', 53rd Floodplain Management Association Conference, Tweed Heads, 28 - 31 May 2013, pp. 13.

[*First page of conference paper*]

Publication 2
Wenger, C., Hussey, K. and Pittock, J., 2013. *Living with Floods: Key Lessons from Australia and Abroad*, National Climate Change Adaptation Research Facility, Gold Coast, Australia.

[*Report cover and the first page of section 6.2: The Netherlands case study*]

Publication 3
Wenger, C., 2013. *Climate Change Adaptation and Floods: Australia's institutional arrangements*, National Climate Change Adaptation Research Facility, Gold Coast, Australia.

[*Report cover, preface and the first page of text reproduced in the thesis. Note that section 1, the executive summary, was not included in the main body of the thesis so the publication format provided below begins with section 2 of the report. The executive summary formed the basis of a conference paper found at Appendix 5*].

Publication 4
Wenger, C., 2014. Sink or Swim: alternative approaches to flood disaster reconstruction and mitigation. In: *River Basin Management in the Twenty-First Century: understanding people and place*, (Eds, Squires, V., Milner, H. and Daniell, K.), CRC Press, Boca Raton, Florida, pp. 418-445.

[*Book cover and first (double) page of Chapter 18 of the book*]

Publication 5
Wenger, C., 2015. Better use and management of levees: reducing flood risk in a changing climate, *Environmental Reviews,* **23**(2): 240-255. doi:10.1139/er-2014-0060.

[*First page of journal article*]

Publication 6
Wenger, C., 2015. Building walls around flood problems: the place of levees in Australian flood management, *Australian Journal of Water Resources,* **19**(1): 3-30. doi:10.7158/W15-008.2015.19.1.

[*First page of journal article*]

Publication 7
Wenger, C. [under review]. The oak or the reed: how resilience theories are translated into disaster policies. *Ecology and Society*, submission number ES-2016-8425.

[*Publication format not yet available*]

LIVING WITH FLOODS: KEY LESSONS FROM FOUR AUSTRALIAN FLOOD REVIEWS AND SIMILAR REVIEWS FROM THE NETHERLANDS, CHINA AND THE USA

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ABSTRACT

2010-2011 saw some of the biggest flood events in Australia's history. The large scale of events prompted numerous inquiries and review processes by different governments and organizations. As climate change is expected to increase the severity and likelihood of flooding events in the future, a project was developed to analyse these reviews and determine if they offered any lessons for climate change adaptation. The project focused on four recent reviews from Queensland and Victoria. The project also compared Australia's review processes and findings with similar processes from the Netherlands, China and the USA to determine points of similarity that reinforced Australian findings and to explore differences.

This paper presents some of the major findings of the reviews. We explore the surprising failure of Australian flood inquiries to address future flood risks from climate change. Conclusions are also drawn as to where Australia is innovating in flood management future and where reforms are needed. Our findings suggest there is potential for Australia to explore ecosystem approaches to flood control, and that reform is needed of land use planning and disaster relief funding. We also look at the adaptive potential of structural and non-structural measures and the role of flood insurance and relocation.

INTRODUCTION AND METHODOLOGY

2010-2011 saw some of the biggest flood events in Australia's history, with approximately 80% of Queensland declared a disaster zone and extensive flooding in other eastern states, notably Victoria. The scale of events, the number of lives lost and the damage incurred prompted numerous inquiries and review processes by different governments and organizations. As climate change is expected to increase the severity and likelihood of flooding events in the future, a project funded by the National Climate Change Adaptation Research Facility was developed to analyse reviews and determine if they offered any lessons for climate change adaptation (Wenger et al., *forthcoming*). This paper summarises findings from that project.

Four Australian flood reviews were analysed in depth for the project:

- Brisbane City Council's Flood Response Review Board report, or 'Brisbane Review' (Arnison et al., 2011)
- Queensland Floods Commission of Inquiry, or 'QFCI' (QFCI, 2012, QFCI, 2011)
- Victorian Review of the 2010-11 Flood Warnings and Response, or 'Comrie Review' (Comrie, 2011)
- Parliament of Victoria's Environment and Natural Resources Committee Inquiry into Flood Mitigation Infrastructure in Victoria, or 'ENRC Inquiry' (Parliament of

NCCARF
National
Climate Change Adaptation
Research Facility

Synthesis and Integrative Research
Final report

Living with floods: Key lessons from Australia and abroad

Caroline Wenger, Karen Hussey
and Jamie Pittock

6.2 The Netherlands

6.2.1 The resources selected

The primary references for the Netherlands were selected by the research team on the basis of their influence and/or innovation.

A key resource used was *Working Together with Water: A Living Land Builds for Its Future – Findings of the Deltacommissie* (Deltacommissie [Delta Committee] 2008)

The first Deltacomissie was formed following disastrous floods in 1953. That committee introduced risk-based approaches to flood protection and focused on engineering works to address threats. The report of the Deltacomissie2008 is the second major nationwide review of Netherlands flood defences. The second Deltacomissie was appointed not in response to a past flood event, but specifically to address future flood threats to coastal regions due to climate change.

The *terms of reference* of this review are expressed as a broad mandate:

> The committee's task is to advise the Secretary of State on:
>
> a. expected sea level rise, the interaction between that rise and the discharge in the major rivers in the Netherlands and such other developments, climatological and societal, until 2100–2200 as are important for the coast of the Netherlands;
>
> b. the consequences of such developments for the Dutch coast;
>
> c. possible strategies for an integral approach leading to sustainable development of the Dutch coast, based on a) and b) and
>
> d. to indicate the additional value to society of such strategies, in addition to the safety of the hinterland, in both the short and long term. (Deltacomissie 2008)

The terms of reference are expanded upon in a two-page explanatory note that emphasises the driving threat of climate change. It directs the Committee to identify future opportunities as well as threats; to consider temporal and spatial effects of options on the environment; to consider interactions between coast and rivers; and to take an intersectorial approach. There is an emphasis on innovative measures: 'creativity, imagination, and the ability to think outside existing contexts' (pp. 101–4).

The terms of reference are thus very broad and open-ended, leading the Deltacommissie to describe not only its mandate but also how the Committee interpreted it. The Committee described its task as 'how the Netherlands can be made climate proof over the very long term: safe against flooding, while still remaining an attractive place to live, to reside and work, for recreation and investment'. This articulates the mandate in terms of core societal values.

Climate change adaptation and floods: Australia's institutional arrangements

Case Study

Caroline Wenger

PREFACE

Climate change adaptation and floods is a case study that contributed to a broader climate change adaptation project. The case study used project methodology developed by Karen Hussey, Steve Dovers and Richard Price. Details of the umbrella project are:

> Hussey, K, Price, R, Pittock, J, Livingstone, J, Dovers, S, Fisher, D & Hatfield-Dodds, S 2013,*Statutory frameworks, institutions and policy processes for climate adaptation: Do Australia's existing statutory frameworks, associated institutions and policy processes support or impede national adaptation planning and practice?*, National Climate Change Adaptation Research Facility, Gold Coast, 193 pp.

The case study also drew upon work undertaken as part of a second NCCARF project under its synthesis and integrative program (referred to in this paper as the SIRP Report):

> Wenger, C, Hussey, K & Pittock J 2013, *Living with floods: Key lessons from Australia and abroad*, National Climate Change Adaptation Research Facility, Gold Coast, 267 pp.

The author would like to thank Jamie Pittock, Karen Hussey and Richard Price for valued feedback on the initial draft.

2. OBJECTIVES OF THE RESEARCH

2010-2011 saw some of the biggest flood events in Australia's history, with approximately 80% of Queensland declared a disaster zone and extensive flooding in other eastern states, notably Victoria. Flooding is Australia's most expensive natural hazard and the federal government allocated 5.6 billion in recovery funding to Queensland alone, primarily to restore public infrastructure (BITRE, 2008, Gillard, 2011). Climate change scenarios predict an increase in intensity and frequency of flooding, potentially exposing Australia to even greater damages in the future. Floods are thus a key area for improving adaptive capacity.

The large scale of events, the number of lives lost and the scale of the damage incurred prompted numerous inquiries and review processes by different governments and organizations. Flood research for a related project by the same author analyzed four Australian flood reviews[1] to determine if they offered any lessons for climate change adaptation (Wenger et al., 2013). The project identified inadequacies in institutional and regulatory arrangements, development planning and funding mechanisms and overwhelmingly pointed to the need for improvements in non-structural measures, particularly in the preventative phase of emergency management. It also found that adaptive approaches that are proving successful and cost effective overseas are largely unknown in Australia, and would have difficulty being implemented under current arrangements.

Accordingly, this paper will explore flooding from the perspective of government function to determine:

- current policies and institutional arrangements in place to address flooding
- the types of reforms that would be required to reduce Australia's vulnerability to flooding in the future.

Floods should not be seen merely as disasters. Australia's carryover water storage system depends on them. Managed well, flooding can replenish groundwater, restore ecosystems and boost economies. How Australia manages floods will be vital for its adaptation to other climate change impacts such as drought.

Prevention, Preparation, Response and Recovery, otherwise known as PPRR, is the standard emergency management framework currently used in Australia (COAG, 2011, EMA, 2004). Its advantage, as well as being widely understood by flood managers, is that it divides disaster management into temporal phases. Research indicates that proactive intervention in the prevention stage, is more effective and cost efficient than interventions at later stages (BTRE, 2002, Wenger et al., 2013). The emphasis of this paper is therefore on flood prevention.

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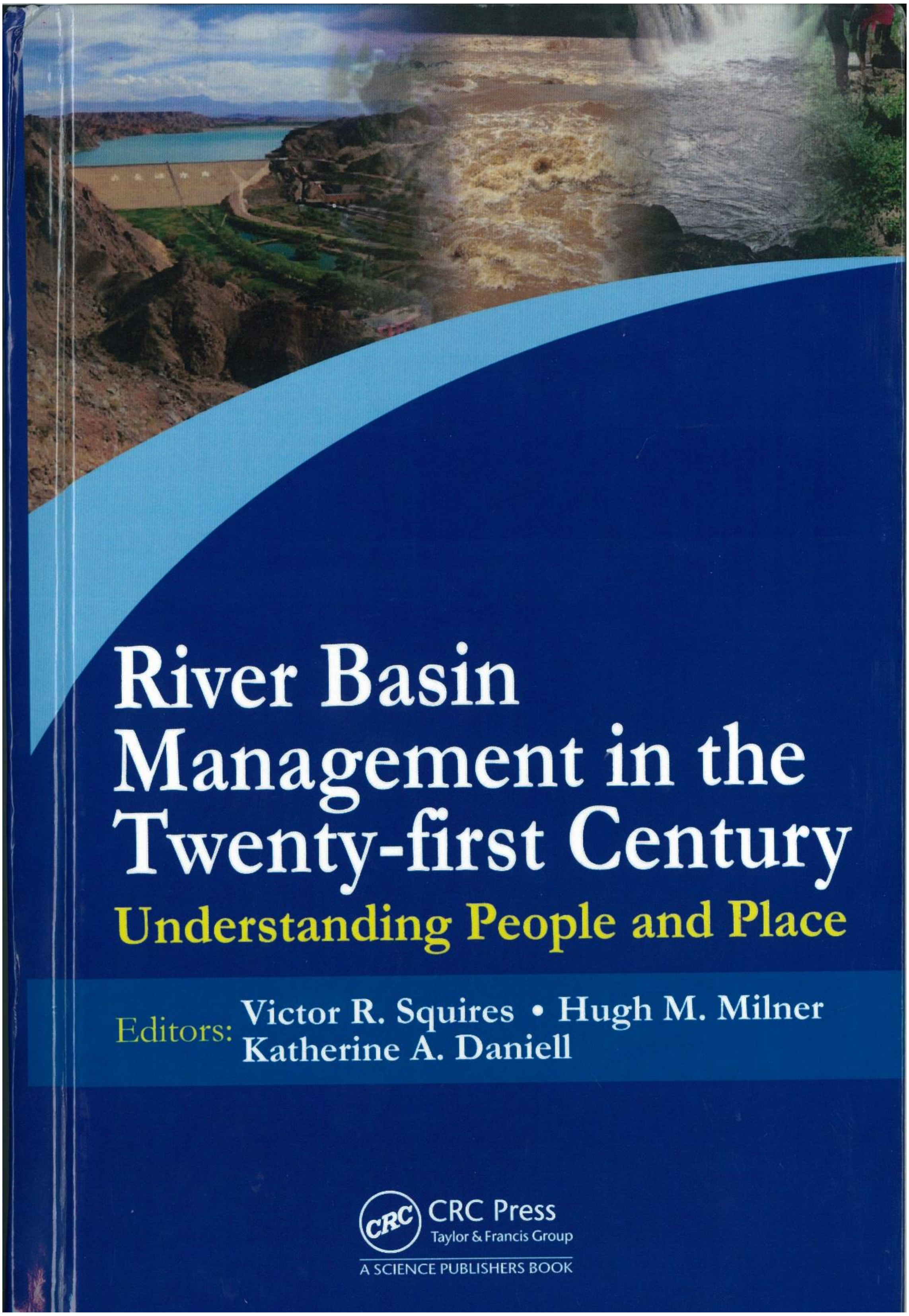
[1] Australian reviews studied for the SIRP report include: the Queensland Floods Commission of Inquiry (referred to in this report as the QFCI); the Victorian Review of the 2010-11 Flood Warnings and Response (referred to in this report as the Comrie Review); the Brisbane Flood January 2011: Independent Review of Brisbane City Council's Response; and the Environment and Natural Resources Committee Inquiry into Flood Mitigation Infrastructure in Victoria (referred to in this report as the ENRC Inquiry). Other reviews were referenced but not studied in depth.



River Basin Management in the Twenty-first Century
Understanding People and Place
Editors: Victor R. Squires • Hugh M. Milner
Katherine A. Daniell
CRC Press
Taylor & Francis Group
A SCIENCE PUBLISHERS BOOK

18

Sink or Swim: Alternative Approaches to Flood Disaster Reconstruction and Mitigation

Caroline Wenger

SYNOPSIS

Climate change and population growth are expected to worsen flooding globally, leading to escalating recovery costs that countries can ill-afford. Improving disaster resilience as part of post-disaster recovery is crucial to minimising these losses.

The first section, *Building Back Better*, looks at disaster costs following recent Australian floods. It examines post-disaster reconstruction policies in three different countries and the legislative and funding provisions that support them. Relocation is identified as a significant strategy in some countries.

Ecosystem Approaches to Flooding highlights an innovative resilience strategy used in many parts of the world that not only reduces flood risk but is also expected to buffer the effects of climate change. It generally involves relocation or changing land use. Discovering what makes a successful relocation scheme is thus important to implementing this approach. In contrast to some of the other countries studied in this chapter, achieving relocation in Australia is a challenge. Recent Australian examples of relocation are studied in the final section, *Relocation Policies in Australia*, and timing, funding, and social factors are all found to be significant for success.

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In the *Discussion*, lessons are drawn from all sections and countries on how to achieve improved flood resilience, particularly for countries such as Australia, where barriers such as cost impede the incorporation of betterment into post-disaster reconstruction.

Keywords: Australia, China, Dongting lake, ecosystem approaches, flood hazard mitigation, floodplains, land swap, legislation, levees, Murray-Darling Basin, New South Wales, polders, post-disaster reconstruction, Queensland, Regge River, risk assessment, 'room for river' measures, sea level rise, The Netherlands, USA, Victoria, wetland, Yangtze River

1 Introduction

Legally, rivers are defined by their banks, but in ecological terms, rivers also consist of the areas they occasionally swell into: their floodplains, ephemeral tributaries and anabranches (Taylor and Stokes 2005; Wenger et al. 2013). Perhaps because humans and rivers exist within different timescales, people think of such areas as being land and rarely recognize them as being part of the river. Floodplains attract settlement because of their alluvial fertility, access to drinking water, river transport, and resources such as fish. However, these bounties come at a cost and periodic inundations destroy assets, lives and livelihoods. Over time, towns and cities may form around vulnerably-located pioneer dwellings, land use changes and exposure to flood grows (Smith 1998; Squires, this volume).

Floods are a consequence of a complex interplay between climate, hydrological cycles, catchment topography and human land management. Factors that can worsen flooding of human settlements include:

- **narrow catchments or bottlenecks:** water has less room to spread and can rise rapidly and to great depth even in modest floods
- **dry catchments, vegetation clearance and urban development:** increase the amount and speed of run-off, and increase erosion and sediment movement
- **subsidence:** can be caused by extracting groundwater or draining wetlands
- **hotter climates:** higher sea surface and air temperatures result in greater evaporation and an increased water holding capacity of the air. Thus greater quantities of rain fall in intense bursts. Continental ice melt raises sea levels. Seasonal snow melt accelerates, flooding river valleys
- **structural measures to prevent flooding such as flood levees and flood gates:** cut off rivers from their floodplains and wetlands, reducing the overall flood storage capacity of the landscape

NRC Research Press

REVIEW

Better use and management of levees: reducing flood risk in a changing climate

Caroline Wenger

Abstract: Many nations rely on dykes and levees to mitigate flood risk. However, a myriad of problems has prompted views that levees are ultimately maladaptive and should be used as a measure of last resort. This leads to questions not only about the place of levees in future flood risk management, but also whether anything can be done to reduce their impacts. A detailed review of flood events from Australia, China, the Netherlands, and the USA was used to develop a case study for each country. Case studies present existing levee problems, future flood threats, and national strategies to address them. These were used as a basis to analyse the transferability of adaptive flood approaches. While many countries are attempting to restore floodplain storage, thereby reducing their reliance on levees, others are increasing their investment in levee construction. This review explores factors that affect the transferability of adaptive approaches, including issues, such as problem recognition, affordability, and program delivery. It was found that countries vary in their ability to recognise levee problems, and the level at which decisions are made influences the likelihood of adaptive solutions being adopted. Analysis suggests that federal systems face particular challenges and their capacity to adopt adaptive approaches may be impaired if institutional barriers are not addressed. Regardless of the overall approach to manage flood risk, the experiences of all case study countries offer some broadly applicable lessons for improving the use and management of levees, reducing their adverse impacts, and improving the integration of natural flood mitigation.

Key words: adaptation, climate change, floods, levees, policy transfer.

Résumé : De nombreux pays comptent sur les digues et les levées pour atténuer le risque d'inondation. Cependant, une myriade de problèmes a incité la vue que les digues pourrait finalement être inadaptées et devraient seulement être utilisées comme une mesure de dernier recours. Cela conduit à des questions non seulement sur le rôle des digues pour le futur management des risques d'inondation, mais aussi ce que peut être fait pour réduire leurs impacts. Un examen détaillé de la littérature des crues en Australie, en Chine, aux Pays-Bas et aux Etats-Unis a été utilisé pour développer une étude de cas pour chaque pays. Les études de cas révèlent des problèmes pour les digues existantes, les menaces de futures inondations et les stratégies nationales pour y remédier. Elles ont été utilisées comme base pour analyser la transférabilité des approches adaptatives pour réduire les risques d'inondations. Il a été constaté que, bien que de nombreux pays tentent de rétablir la plaine inondable de stockage, réduisant ainsi leur dépendance à l'égard des digues, que d'autres augmentent leurs investissements dans la construction de la digue. Cet examen explore les facteurs qui influencent la transférabilité des approches adaptatives, y compris des questions telles que la reconnaissance du problème, l'accessibilité et la prestation du programme. Il a été constaté que les pays varient dans leur capacité à reconnaître le problème des digues et que le niveau auquel les décisions sont prises impacte sur la probabilité que les solutions adaptées soient adoptées. L'analyse suggère que les systèmes fédéraux confrontés à des défis particuliers et leur capacité à adopter des approches adaptatives peuvent être compromis par des obstacles institutionnels s'ils ne sont pas pris en compte. Indépendamment de l'approche globale de gestion des risques d'inondation, les expériences tirées de tous les pays étudiés offrent des leçons largement applicables pour améliorer l'utilisation et la gestion des digues, la réduction de leurs impacts négatifs et l'amélioration des mesures naturelles pour atténuer les crues.

Mots-clés : adaptation, changement climatique, digues, inondations, transfert de politiques.

1. Introduction

Floodplains are one of the most valuable land types for human occupation, but systematic encroachment has degraded them, causing the decline of water quality, biodiversity, and soil health on a global scale. River regulation, including water diversion, drainage, impoundment, and levee building, interferes with natural flow regimes and prevents the interaction of rivers with their floodplains, constituting a serious global threat to riparian ecosystems (MEA 2005; Tockner et al. 2008). Population growth will magnify these problems, as more floodplain land is converted to agricultural use and urban development.

As well as degrading natural resources, floodplain encroachment increases flood risk. More assets are exposed to flood hazards, while land clearance, wetland destruction, and urbanisation reduce the landscape's natural ability to absorb water and attenuate floods. This causes faster runoff, deeper floodwater, more rapid flood peaks, and higher velocity (Jones 2000; Rutherfurd et al. 2007; Tockner et al. 2008; Zhou et al. 2013). Risks are exacerbated by climate change, which is expected to increase the scale and frequency of flooding in most of the world's major river basins (Hirabayashi et al. 2013; IPCC 2013). This will put pressure on human settlements and associated infrastructure built to accommodate historic patterns of rainfall. Flood defences may be overcome more frequently and sewerage and drainage systems may be inadequate, with those already disadvantaged expected to

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Building walls around flood problems: The place of levees in Australian flood management*

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The Bushfire and Natural Hazards Cooperative Research Centre, East Melbourne, Victoria

ABSTRACT: *Recent Australian floods have resulted in many changes to levee provisions in Queensland, Victoria and New South Wales. It is therefore timely to review levee issues and current state arrangements. This paper investigates the use of levees as an adaptation measure to address climate change. It also looks at the performance and reliability of Australian levees, environmental impacts, and the relationship between levees and the development of flood prone land. Despite recent changes, there continues to be much scope for improving floodplain development planning and the assessment and management of levees. Development controls continue to be inadequate and this will fuel future demand for levee protection, while lack of development controls behind levees is likely to lead to greater consequences when levees fail, a scenario more likely due to loss of climate stationarity. While levees provide incremental adaptation, they do not offer a long-term solution. However, transformational adaptation measures used in many places overseas are poorly supported by Australian funding programs. Long-term adjustments need to be planned and funded and appropriate incentives and decision-making structures need to be put in place.*

KEYWORDS: Adaptation; climate change; floodplain management; flood mitigation; flood policy; levees.

REFERENCE: Wenger, C. 2015, "Building walls around flood problems: The place of levees in Australian flood management", *Australian Journal of Water Resources*, Vol. 19, No. 1, pp. 3-30, http://dx.doi.org/10.7158/W15-008.2015.19.1.

1 INTRODUCTION

In 2010-2013, eastern Australia experienced widespread, major flooding and unprecedented damage bills. This led the Intergovernmental Panel on Climate Change (IPCC) to conclude that "Australia has a significant adaptation deficit in some regions to current flood risk" (IPCC, 2014). Following the floods there have been numerous inquiries at all levels of government and a significant reassessment of legislation, policy and programs relating to disaster management. The push for reform is driven not only by the high cost of recent damages but the expectation that future damages will rise still further due to climate change and population pressure (Deloitte, 2013; Productivity Commission, 2014).

The Productivity Commission's draft report on disaster funding highlights an imbalance between disaster prevention and post-disaster funding (Productivity Commission, 2014). The Commission proposes that funding for prevention be significantly increased from its current approximately A$30 million per year to $200 million per year. It also recommends removing prescriptive funding conditions, to give states and local government greater spending autonomy. This would apply to both mitigation and recovery funds, which could dramatically increase the funds available for prevention. This raises the crucial question of how that money would be spent.

Adaptation theorists argue that large scale engineering solutions to floods tend to have highly localised, short-term benefits that are often maladaptive across broader scales and sectors (Adger et al, 2005; Barnett & O'Neill, 2013; Cardona et al, 2012). Engineering responses such as levees are often characterised as "incremental" adaptation and while this may be

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Appendix 2: Interview topic guide

Project: Living with Floods: key lessons from Australia and abroad

Record:

- Date
- Interviewer
- Interviewee name and contact details
- Interviewee code (e.g. #FPM, #EM, #INS, #LGA)

A. Introduction to the interview process

- Thank interviewee for their time.
- Confirm that they have received the project information sheet.
- Repeat that this research is examining responses to the 2010-11 floods in eastern Australia and the applicability of inquiry outcomes to climate change adaptation.
- Note that we would like to spend between an hour and an hour and a half asking questions in a semi-structured format and that we want to record the conversation.
- Explain confidentiality and determine whether or not they agree to have comments attributed to them/their position; that we would seek to contact them to verify accuracy should we wish to attribute a quote to them; and that they may withdraw at any time.
- Explain the purposes of recording the interview and verify if this is acceptable.
- Ask if they have any questions about the research.
- Ask them to sign the consent form.
- The following are questions designed to elicit open-ended responses which will then be followed up with specific questions that are not on this list.

B. Introductory questions, to establish rapport, expertise and interests

1. I understand that you have worked on [emergency management / floodplain management / insurance industry / local government] for some time, in what capacities?

2. How many years have you worked on [emergency management / floodplain management / land use planning / insurance industry / local government]?

C. Questions on flood inquiries

3. Which of the recent flood inquiries are you familiar with?

   - Brisbane City Council's Flood Response Review Board report (May 2011);
   - Queensland Floods Commission of Inquiry (interim report Aug. 2011, final report Feb. 2012);
   - Victorian Review of the 2010-11 Flood Warnings and Response (interim report Jun. 2011, final report Dec. 2011); and
   - Parliament of Victoria's Environment and Natural Resources Committee Inquiry into Flood Mitigation Infrastructure in Victoria (report by May 2012).

4. What are your views on the outcomes of flood inquiries, above and beyond that which is evident in the written reviews, including:

   - which key inquiry findings and lessons need to be reinforced and why; and
   - whether any important lessons or outcomes were not covered by the inquiries.

D. Questions on efficacy of different measures for climate change adaptation and priorities

5. Do you have any opinions on how Australia should to adapt to a climate change scenario that predicts floods of changing frequency or magnitude:

- the type of measures most likely to assist adaptation to less predictable flood events;
- the type of measures or approaches to avoid;
- any perceptions regarding institutions, emergency policies or organisational structures that could help Australia to manage flood events that are less predictable;
- resourcing mechanisms suitable for less predictable flood events (for both prevention / preparedness and response / recovery phases); and
- barriers and opportunities for communities wishing to reduce their risk and vulnerability to less predictable flood events.

6. Can you suggest any case study opportunities for points you have made?

E. Questions on communication of results to user groups

7. What do you think would be the most effective methods of communicating lessons for climate change adaptation and limits to adaptation in your industry [emergency management / land use planning / floodplain management / insurance industry / local government]

F. Conclusion

8. Is there anything else you would like to tell us?
   - Outline plans to complete this research in late 2012 for project report and academic publication.
   - Offer to forward a copy of the final research.
   - Thank them for their time and help.

Follow up

- Within a few hours of the interview, make notes on the interview in terms of key points made by the interviewee, new ideas, and the interviewer's impressions.
- Within a few days, send a follow up e-mail thanking the interviewee for their time and repeating the proposed 2012 publication date.
- Later, transcribe the interview for analysis.
- In late 2012, provide the interviewee with a copy of the final publication.

Appendix 3: Communication of results

Oral Presentations

National Water Commission
"Living with Floods: key lessons from Australia and abroad"
29 October 2013
(presented with Jamie Pittock)

Fenner School of Environment and Society
"Flood management in a changing climate"
19 February 2014
(PhD milestone seminar)

54th Floodplain Managers Association National Conference, Deniliquin
"Climate Change Adaptation and Flooding: Australia's Statutory and Institutional Arrangements"
23 May 2014

The Hydrological Society, Canberra and the International Association of Hydrogeologists, Canberra
"Flood management in a changing climate"
1 July 2014
(awarded: prize for 'Best Student Talk')

National Climate Change Adaptation Research Facility Annual Conference, Gold Coast
"Building Walls Around Flood Problems: lessons from four countries"
Panel session 4 - How can we manage the risks of flooding related to climate change?
30 September 2014
(Chair: Jamie Pittock; panelists Gerry Galloway, Susan Hunt, Caroline Wenger)

Fenner School of Environment and Society
"Flood management in a changing climate"
25 March 2015
(PhD milestone seminar)

Three Minute Thesis Competition
"Immovable oaks and unbreachable dykes"
Science Colleges 3MT competition, Finkel Lecture Theatre:18 August 2015
(awarded: CMBE People's Choice award; CMBE Runner-up)

ANU Open Day, Haydon-Allen Tank: 29 August 2015
ANU Final Llewellyn Hall, School of Music: 16 September 2015
(can be viewed at: https://www.youtube.com/watch?v=XEbZnJ3wW2A)

AFAC and Bushfire & Natural Hazards CRC Conference 2015, Adelaide
"Immovable oaks and unbreachable dykes"
2 September 2015

Fenner School of Environment and Society
"Symbiotic relations in flood management"
4 May 2016
(PhD milestone seminar)

The Hydrological Society, Canberra

“Symbiotic relations in flood management”
5 July 2016

Posters

AFAC and Bushfire & Natural Hazards CRC Conference 2014, Wellington, 2-5 September 2014
“Flood management in a changing climate”

AFAC and Bushfire & Natural Hazards CRC Conference 2015, Adelaide Convention Centre, 1st - 4th September 2015
“Is ‘resilience’ the same as ‘adaptation’?”

Bushfire and Natural Hazards CRC Research Advisory Forum, Hobart, 11-12 May 2016; AFAC and Bushfire and Natural Hazards CRC Conference 2016, Brisbane, 30 August-1 September 2016
“Policy transfer: between countries, between disciplines”

Other

17th International River*symposium,* Canberra
15 - 18 September 2014
Book launch event and information booth for “River Basin Management in the Twenty-first Century” (with other authors: Richard Kingsford, Emmeline Hassenforder, Benjamin Noury)

FLOOD MANAGEMENT IN A CHANGING CLIMATE

Caroline Wenger[1]

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FLOODING IS AUSTRALIA'S MOST EXPENSIVE NATURAL HAZARD AND RECORD DAMAGES resulting from the 2010-11 floods reflect global trends. Climate change scenarios predict that flood intensity and frequency will increase, potentially exposing Australia to even greater damages in the future. Floods are therefore a key area for improving adaptive capacity.

OBJECTIVES

This research aims to determine how best to adapt to future flood threats by analysing recent flood events and management approaches in Australia, USA, China and the Netherlands.

- What are the strengths and weaknesses of Australian flood management ?
- Are our institutions able to accommodate future flood threats ?
- Can we transfer innovative approaches from overseas ?
- Will resilience policies lead to adaptive outcomes ?

METHODS

- Literature review
- Interviews
- Case studies

PRELIMINARY FINDINGS

Is Australian flood management effective?

Prevention is a priority for adaptation in Australia, including land use controls and relocation (IPCC 2014).

This research aims to determine how best to adapt to future flood threats by analysing recent flood events and management approaches in Australia, USA, China and the Netherlands.

Australia continues to develop flood prone areas; multiple conditions and exemptions hamper application of development legislation and planning provisions.

Development tools, such as DFL, do not incorporate anticipated future risks.

National recovery arrangements are insufficient and expose Australia to repeat damage costs.

Funding for mitigation is minimal.

Bad decisions are hard to reverse!

Should we put in more dams and flood levees?

Structural mitigation can reduce exposure to low and medium sized floods. However, it increases vulnerability to major floods. Levees and dams facilitate ongoing development of flood prone land, exposing more assets to risk. Levees also increase erosion and the severity of flooding elsewhere in the catchment. This impacts other communities, drinking water quality, riparian and marine ecosystems and natural resource dependent industries.

Recent floods have resulted in a push for more flood levees.

Is community resilience the answer?

Recent floods demonstrate that the capacity of emergency services is stretched in a major flood event. Increasing community self-reliance is therefore a sensible adaptation measure if it can be achieved. However disadvantaged groups have limited financial means to implement prevention or to recover.

Risk awareness is no substitute for effective flood development controls.

What about flood response?

Reviews recommend improving flood warning systems, especially for flash flood, and greater interoperability between response agencies. Joined-up capacity is a logical solution for coping with major disasters. However 'all hazards, all agencies' has been an Australian policy objective since 1989 and reviews make it clear that this has not yet been achieved.

Prevention is better than cure.

What are they doing overseas?

The Netherlands, the USA and China rely on traditional mitigation, such as levees and channel modification. Recent exceptional floods have prompted countries to reassess their approach to flooding. They believe levees will be insufficient to address future threats. Reviews also highlight high maintenance, administrative and external costs. These countries are strengthening strategic levees, but they are also trying to reduce their reliance on them. Examples include:

- Removal or re-alignment of levees to increase floodplain area;
- Reversal of past land reclamation using relocation, property elevation and flood-compatible land use;
- Restoration and reconnection of wetlands and river channels to provide natural flood storage;
- Integrated water resource mgt.

Research is investigating the transfer of adaptive approaches to Australia.

ACKNOWLEDGEMENTS

Jamie Pittock, Katherine Daniell, Steve Dovers, Michael Eburn, Karen Hussey for past and present supervisory support; NCCARF for funding initial research; & BNHCRC Research Manager
michael.rumsewicz@bnhcrc.com.au

Floods don't have to be disasters: urban planning in Canberra

Australian National University

bnhcrc.com.au

IS 'RESILIENCE' THE SAME AS 'ADAPTATION'?

Caroline Wenger[1]

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FLOODING IS AUSTRALIA'S MOST EXPENSIVE NATURAL HAZARD. CLIMATE CHANGE SCENARIOS predict increasing flood intensity and frequency. This potentially exposes Australia to greater damages in the future, making flood management key to improving adaptive capacity. This research explores whether 'resilience' strategies will result in outcomes that are truly adaptive.

RESEARCH QUESTIONS

Which approaches to flood management best enable us to respond to changes in climate and population?

Can we transfer innovative approaches used overseas?

Are there implementation barriers? Is reform needed?

Will the resilience approach adequately address future flood threats?

FINDINGS TO DATE: OVERSEAS

Australian approaches to flooding were compared with Netherlands, China & USA.

Overseas: a shift from 'control the river' to 'room for the river' strategies.

This 'transformational' change includes measures such as:

- relocation
- housing design
- flood-compatible land use & livelihoods
- ecosystems based approaches
- basin-scale integrated water resource management

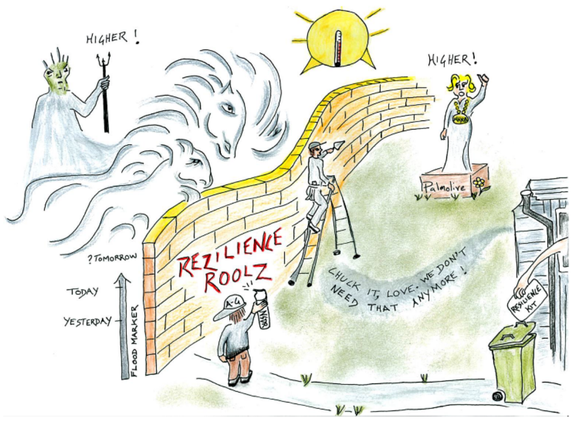
ENDUSER STATEMENTS

"This research has the potential to identify new risk treatments and outline the institutional and social changes required to enable them to be implemented in Australia. These outputs would assist in ensuring that risk treatments assessed in Floodplain Management Studies and included in Floodplain Management Plans build resilience to current and future risks."

Chris Irvine
SES Tasmania

"Governments at both federal and state level are placing greater policy emphasis on promoting resilience in the face of natural disasters. Translating this into community action is a significant challenge, especially when coupled with environmental and demographic change. Research that helps make this approach less haphazard will be welcomed across the emergency management sector."

John Schauble
Emergency Management Victoria



FINDINGS TO DATE: AUSTRALIA

Australian 2012 flood reviews looked backwards and failed to consider future threats such as climate change.

Australian decision-making processes and institutional arrangements favour traditional flood control approaches.

Continuing development of flood prone areas will fuel future demand for levees.

Using adaptation criteria, levees appear maladaptive over the longer term.

Levees are an incremental adaptation measure that extend the amount of time that 'business as usual' can occur: a temporary solution.

Long term adjustments also need to be planned and funded.

Risk awareness is no substitute for effective flood development controls.

Relocation needs to be incorporated into post-disaster reconstruction programs to improve long-term resilience

A RESILIENT *STATUS QUO* MAY PREVENT LONG TERM ADAPTATION

Find out more: a publications list, including some free downloads, at:
http://fennerschool.anu.edu.au/about-us/people/caroline-wenger#acton-tabs-link--tabs-0-middle-3

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bushfire&natural HAZARDS CRC
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NCCARF National Climate Change Adaptation Research Facility

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POLICY TRANSFER: BETWEEN COUNTRIES, BETWEEN DISCIPLINES

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FLOODING IS AUSTRALIA'S MOST EXPENSIVE NATURAL HAZARD. CLIMATE CHANGE SCENARIOS predict increasing flood intensity and frequency. This potentially exposes Australia to greater damages in the future, making flood management key to improving adaptive capacity. This research explores whether 'resilience' strategies will result in outcomes that are truly adaptive.

RESEARCH QUESTIONS

- Which flood management approaches are most adaptive to future scenarios ?
- Can we transfer innovative approaches used overseas ?
- Will the resilience approach adequately address future flood threats ?

POLICY TRANSFER BETWEEN COUNTRIES

Is it possible to transfer adaptive flood management policies that appear successful elsewhere to Australia ?

Ecosystem-based approaches are highly adaptive but are little recognized in Australia. They reduce flood risks and usually have co-benefits (e.g., Leeton case study: new tourism ventures, biodiversity and youth training).

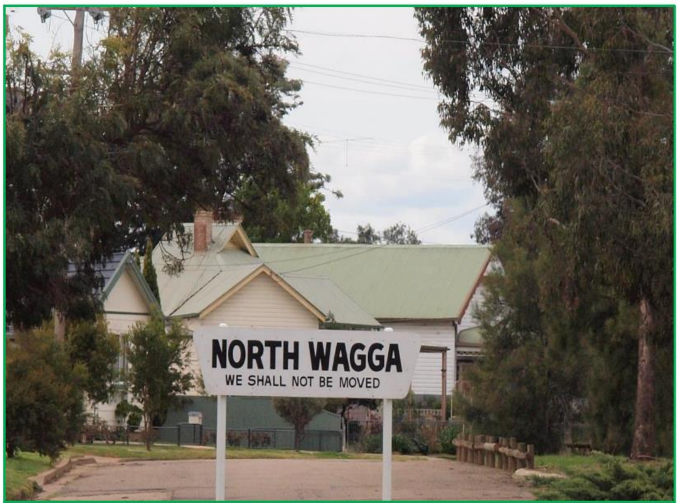
In some cases, ecosystem-based measures require the relocation of flood sensitive development. Why is relocation used overseas but so hard to achieve in Australia ?

My research looked at incentives, government program delivery, cost and timing. It drew on examples of relocation in Australia (including Grantham, QLD) and overseas (NL, China, USA).

Other policy transfer issues investigated include barriers to better development planning and factors favouring structural measures.

ADAPTIVE MANAGEMENT OPTIONS, POLICY TRANSFER AND RESILIENCE

Find out more: a publications list, including some free downloads, at: http://fennerschool.anu.edu.au/about-us/people/caroline-wenger#acton-tabs-link--tabs-0-middle-3



Barriers to achieving relocation
Who pays for flood damages ? Who benefits from avoided damage ?
How does program design affect participation ? How can we minimise relocation costs ?

THE LEVEE PARADOX

When investigating adaptive options for flood management, I studied some recent examples of 'the levee paradox' (Smith 1998), whereby structural mitigation facilitates further development of hazardous areas. This leads to increased assets in the wrong place and greater consequences when levees fail.

The paradox also applies to dams, including Wivenhoe Dam, QLD.

The levee paradox is a resilient feedback loop and it forms a 'transformational' challenge. My research looks at circumstances where levees might be justified and how feedbacks can be altered to create incentives for change.

RESILIENCE: POLICY TRANSFER BETWEEN DISCIPLINES

The concept of resilience transferred to disaster management from other scientific fields, including engineering and ecological systems. However, these disciplines interpret resilience very differently. One supports stability and *status quo*; the other accommodates system variability. Applied to flood management, these are associated with different activities.

Research suggests resilience has been superimposed on disaster management frameworks without much analysis. The result is that all management options remain open, regardless of how adaptive they are in the longer term.

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Appendix 4: Climate change adaptation measures for flooding

[Published in: Wenger, C, Hussey, K, Pittock, J, 2013, 'Living with floods: Key lessons from Australia and abroad', National Climate Change Adaptation Research Facility, Gold Coast, pp.264]

Explanatory notes to table of climate change adaptation measures for flooding

The project: Following the 2010-11 floods, several flood reviews were undertaken by state governments and other agencies. A project funded by NCCARF examined four of these reviews to determine if they offered lessons for climate change adaptation. To gain further insight, Australian flood professionals were interviewed and approaches to flooding in China, USA and the Netherlands were investigated (Wenger, Hussey *et al*. 2013). This table summarises findings of the project, with the aim of assisting decision makers to assess the most suitable adaptive measure for their situation. The standard emergency management framework is used to divide measures into prevention/mitigation, preparation, response and recovery (PPRR), offering interventions at different phases of the emergency management cycle.

Changing flood characteristics

Effects of anthropogenic climate change are superimposed on natural variation which can play out over many decades. Warmer sea surface temperatures are expected to increase water evaporation and warmer air is able to hold more water vapour, resulting in more intense rainfall. Flood characteristics that may change include:

- geographic location
- frequency (of both large and small events)
- timing (seasonal)
- magnitude (e.g. volume, depth, area inundated, precipitation intensity, rate of rise, velocity)
- Flood duration

Some variables have a greater effect on flood risk than others. For example, seasonal changes may be relevant to the agricultural sector and the timing of emergency planning but may not to alter risks more generally. Characteristics such as flood frequency, magnitude and duration are also increased by land development, which is expected to continue in coming decades.

Australian flood reviews studied for this project focused on past events and did not assess the adequacy of existing strategies to address future risks. The relevance of review recommendations to climate change therefore had to be assessed. This was done by looking at possible changes to flood characteristics and the effect proposed measures would have on them.

Which measures are adaptive

Hallegatte's strategies, summarised below, are used to help assess the adaptive potential of proposed measures (Hallegatte 2009Hallegatte 2009). These strategies can help address changing flood patterns regardless of whether this is due to anthropogenic climate change or long term natural variability. Being low cost and flexible, they do not rely on information certainty or accurate local scale modelling.

- **No-regrets strategies:** beneficial even without additional climate change risks
- **Flexible:** for example, measures that are easily reversible, or modified
- **Low cost:** including structure / technology designs that enable low-cost modifications
- **Soft strategies:** such as information, capacity, institutional or policy, and also ecosystem-based adaptation like floodplain restoration (hard strategies include technology and structures)
- **Avoiding long-term commitment:** uncertainties increase further into the future so this gives flexibility to adapt to new circumstances while continuing to use land in the short term
- **Synergies:** that consider positive and negative externalities to other sectors and stakeholders

Maladaptive measures often prioritise short term gains over long term resilience. They are generally inflexible, costly to reverse and increase long-term vulnerability.

Table A.4.1: Living with floods: adaptation measures

Prevention/mitigation

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
Flood information and risk assessment	Knowledge of risks is a prerequisite for risk avoidance, mitigation and preparation by local authorities, developers and individuals. Planning legislation and instruments can only be applied where flood information exists. Better mapping improves certainty for the insurance industry resulting in actuarially sound premium pricing. Accurate pricing signals level of risk. Large scale mapping can be cost effective (e.g., QRA maps) and help form business cases for more detailed studies. Mapping a range of flood levels up to PMF improves versatility for both development planning and emergency management.	Detailed flood studies can be expensive. Different resolution of mapping can be used according to the needs of different communities. To assess risks, flood likelihood, behaviour and consequence need to be mapped and assessed. These are also important for planning emergency response. Due to cost, likelihood (areal extent) is sometimes the only factor mapped. Flood risk will change as the climate changes requiring iterative mapping. Catchment boundaries, appropriate for flood studies, do not coincide with local government boundaries. Local expertise can be lacking for both production and assessment of information. Flood risk changes in areas where development changes water flows. Many councils are reluctant to release flood information as it may impact property values. The National Flood Risk Information Program may improve availability.	Mapping that includes palaeological information (such as QRA maps) and PMF can help to compensate for Australia's short flood records (at most, 90 years) and enable planning for worst case scenarios. Production of flood information and risk assessment needs to include future climate scenarios, assets and settlement patterns. As climate change projections are revised, risk assessments also need to be updated. No-regrets, soft, low cost options for basic flood mapping.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
New development restricted to areas of low flood risk	Reduces future exposure to high, long-term damage costs and social consequences. Reduces the need for emergency response capacity. Costs less than rectifying bad development decisions via relocation Costs less and is more effective than protecting badly sited development via structural measures (e.g. levees). Land unsuitable for development can be used for flood compatible purposes. USA examples of federal government instruments to encourage local application of development restrictions.	Reduces risks for future development only. Identification of flood risk areas can be hampered by lack or inadequacy of local flood studies and mapping. The most common flood tool used to restrict development is the defined flood level, usually the 1:100 year flood. Work in the USA suggests this is not adequate, particularly for urban areas where consequences of flood and evacuation difficulties are greater. Potential hidden costs: 'down-zoning' can reduce property values and income from rates, raise insurance premiums, and expose local government to liability for compensation. Incentives and support are needed to balance this. Procedures to update planning schemes are complex and lengthy – up to 10 years. Needs reform to enable prompt revision. Legislation relating to indemnity has been amended in some states, but not in others for provision of flood information or zoning revision by councils.	Will help prevent increased damages from larger magnitude and more frequent flooding. Flooding will remain the most predictable hazard in terms of location. However, basing development restrictions on a 'static' 1:100 year flood line may result in people being located in areas of unacceptable flood risk if that flood line moves. Using a more conservative flood line (e.g. 1:500 year for urban areas), and considering MPF, SLR and palaeological information may compensate for lack of stationarity. Revised Australian rainfall and runoff tables are expected to address the incorporation of climate change scenarios. No regrets, flexible / reversible, low cost, soft, avoids long term commitment (of land use). Development of flood risk areas is very difficult to reverse and commits land use for hundreds of years.
Development planning legislation that consistently addresses flood risk	Consistent flood risk requirements in development codes and legislation will reduce ambiguity and exposure to risk.	Application of legislation requires flood information that can be lacking or inadequate. Consistent consideration of flood risk in legislation is currently compromised by non-	Will help prevent increased damages from larger magnitude and more frequent flooding.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
	Risks will be reduced for vulnerable socio-economic groups. Lower risk of pollutants in floodwaters. Greater likelihood that essential services and infrastructure will continue to function during floods. Victorian example where Catchment Management Authorities are designated referral agencies improves the consideration of flood in development planning.	compliance, satellite planning schemes, exemptions, omissions and non-mandatory provisions. Lack of legislation consistency and application often reflects policy conflict. Leadership is needed to resolve this. Flood risk consideration can conflict with: • short term development gains; • affordable housing; • cost of developing flood -free greenfields; • increased rates income; • reducing urban footprints; • regional development objectives; • priority projects; and • infrastructure needs. A financial disconnect in that those gaining short term benefits do not pay the majority of damage costs.	Those already most vulnerable are expected to be disproportionally affected by climate change; providing higher risk ‘affordable’ housing now may be expensive in the long term. No regrets, flexible/reversible, low cost (in the long term), soft.
Construction codes include flood resistant design and materials for buildings, essential services and infrastructure	Where selecting a site free of flood risk is not possible, construction standards increase ability to withstand floods, and to rapidly recover once flooding subsides. Reduces direct flood damage and indirect economic/social losses (eg, downtime, temporary accommodation, health).	Raised floor levels can be an issue for the disabled and the elderly who have to negotiate steps. If building levels are higher than access routes, people may become trapped before realising they need to evacuate. If assessing the suitability of this measure, criteria need to address isolation risks, risk to life and risk of injury as well as asset lifecycles and the economic value of avoided damage.	Raised floor levels are only effective if the level is set sufficiently high and takes future risks into account. Using historical flood data or only raising to the ‘new record’ height may be insufficient. If changing flood patterns extend flood duration, isolation may be a growing issue.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
	It is more cost effective to incorporate flood resilience into new development than to retrofit, particularly long term assets. Planning schemes can impose conditions on rebuilding (e.g., Wagga Wagga). Some retrofit measures are low cost.	Not suitable for areas of more severe flood risk (e.g., high velocity or deep floodwaters). Some design elements (e.g. backflow prevention) may have ongoing maintenance costs. Increased upfront building costs compromise profit margins and affordable housing objectives, which are often prioritised over long term benefits.	No regrets, low cost.
Voluntary relocation (including buy back schemes and land swaps)	Effectively removes people and assets from hazard areas and eliminates future damage. Most viable for repetitively flooded properties that are cheap to purchase. Billions of savings from avoided damages in some US examples. Overseas examples of minimising the cost (e.g. opportunistic pre-purchase of desirable property that can later be used for land swap (NL) Financing opportunities where synergies with other programs (e.g., Lower Loddon buyback). Some costs can be recouped through resale of land (for specified use). 15% US disaster funding has to be used for mitigation, primarily relocation. Reduces future (federal) insurance liability.	Up-front cost is the biggest barrier. Current NDR grants program inadequate to fund this systematically. Insurance payout alone is rarely sufficient to fund relocation, and land use will not change without government involvement. Unlike the USA, Australia does not provide national flood insurance so has less incentive to reduce private damages. Rarely used for entire towns due to expense. Community resistance is common. Land available for relocation is often undesirable or expensive. Needs measures to ensure vacated land is not later redeveloped. E.g., in the USA legislation and strong financial disincentives.	Climate change is expected to result in more frequent floods. As relocation becomes more viable with frequent flooding, this measure may increase in importance. Synergies. High initial cost (long term savings). Not reversible.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
	Vacated land can be put to other uses, including business, amenity, recreation, flood storage (see ecosystem approaches).		
Ecosystem approaches (e.g. 'room for river' floodwater storage; levee setback; wetland restoration and connectivity; riparian vegetation; flood compatible farming systems, SuDS, mangroves)	Mitigates floods for existing development. Reduces flood depth, delays flood peaks and reduces velocity. Results in less erosion, less damage to buildings and infrastructure and greater warning time. Measures primarily need to be implemented in upper catchments (low value land). PES can diversify income for participating property owners. Low on-going administrative costs. Numerous co-benefits (e.g. water quality, ecology, heritage, tourism, recreation, flood compatible business and farming, fisheries, groundwater replenishment). Compatible with integrated water management and win-win outcomes. Is highly effective for small-medium floods. For large floods needs to be used in conjunction with other measures. Commonly used as a measure to adapt to climate change flooding overseas. Australian examples from Leeton, Moreton Bay proposal, Victorian modelling in ENRC Inquiry.	Lack of public understanding about hydrology leads to a common misperception that vegetation and meanders increase flood damage, leading to 'clear and straighten' activities. Ecosystem approaches need coordination across entire catchments but municipal boundaries do not coincide with catchment boundaries. Flood studies, land use, development and flood mitigation are planned and implemented locally. Catchment management is well developed in some states; other states have very poor provisions. Integrated water management can be complex to administer, requires expertise and capacity and is vulnerable to inflexible funding arrangements and siloed approaches. If land is transformed into public park, it needs ongoing public management. Unless ecological benefits are high, identifying a flood compatible private use may be cheaper.	Potential to address multiple climate change problems such as water scarcity (groundwater recharge), pressures on ecosystems and more frequent flooding. Flash flooding is expected to increase due to high intensity rainfall and sparsely-vegetated, drought-affected catchments. Ecosystem approaches slow floods, providing greater warning time. No regrets, flexible, soft, synergies. Cost effectiveness depends on co-benefits, avoided damages, whether land needs to be purchased or use restricted, value of land, etc.
Enabling Betterment	Cost effective in the long term, particularly for areas likely to flood again and in the case of	Rebuilding to improved disaster resilient standards increases the cost of recovery.	Large magnitude floods are likely to occur more frequently with climate change. Recovery costs will also

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
	long term assets: reduces inspection, clean up, repair and replacement costs. Opportunistic adaptation, improving resilience at the point in time it costs the least to do so. Some synergies possible, e.g., bridge raising can have community benefits and improve flexibility of dam releases, reducing erosion (QLD Inquiry). COAG's NSDR supports betterment.	There is no guarantee another flood the same size will occur to justify increased standards. Damaged infrastructure needs immediate restoration. Long-term cost benefit analysis and recovery grants approval processes for betterment are inconsistent with the need for immediate repair. Prior identification of infrastructure that might benefit from betterment could render it ineligible for betterment funding.	recur unless greater resilience can be built into assets. No regrets, lower long term cost (higher short term), some synergies.
Increased proportion of funds for disaster prevention / mitigation	The cost of mitigation is significantly less than the value of avoided damages. Some USA studies indicate very large cost savings. Overseas examples of funding arrangements, eg, USA legislation requires 15% federal disaster relief funding be spent on specified forms of mitigation (eg buy back, house raising). Potential synergies with social, environmental, economic goals. NL example of long term national adaptation strategy that coincides with broader national aspirations; win-win opportunities identified for communities.	Current federal spending on disaster prevention/mitigation is inadequate (~$30 million pa to be spent on resilience, divided by all states and natural disaster types and is not confined to prevention/mitigation). Disproportionate to generous disaster relief and recovery spending. Political barriers: the government that pays for mitigation may not be in power when benefits are realised; negative media coverage for insufficient relief and recovery effort encourages spending. Strong promotion to the public needed on benefits of prevention. Relevant for all Australians (e.g., higher tax and insurance premiums, diversion of government spending from other priorities).	Large magnitude floods are likely to occur more frequently with climate change, which will lead to ever increasing damage bills unless more is invested in prevention. No regrets, significant long term savings, soft, flexible. Potential for synergies, depending on prevention measures chosen and processes to identify win-win opportunities for communities.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
		Selection of mitigation measures needs to consider direct and indirect costs and benefits of measures and their alternatives.	
Levees	Reduces frequency of small to medium flooding for existing development. While levees are high cost, local flood damage is reduced. Best use is to protect compact high value assets (e.g., existing urban and key infrastructure such as electrical and telecommunications facilities) in conjunction with contingency planning and development controls to prevent future need for levees.	High cost to build, repair and maintain levees. Consequences when levees fail are greater than if they had not been there: • Dangerous high energy flooding when breach occurs; • Communities lack experience of smaller floods; and • Perception that land behind levees is safe can a) encourage development, increasing potential damages; b) result in inappropriate building standards, c) inhibit contingency planning. Requires strong administration and on- going commitment: • assessment of off-site and cumulative impacts across catchments when planning; • design standards and approvals; • database of levee location, height, ownership, status; • identification of responsibilities; • maintenance scheduling; • access rights, inspection and audit; • contingency planning; • processes for approval/removal of temporary levees;	Complex flood events can be exacerbated if key infrastructure is flooded, such as electricity sub-stations. Emergency response largely depends on electricity, and the more complex the emergency, the more critical this will become. Levees can protect townships and rural residences against increasing frequency of flooding, though not necessarily increasing magnitude. Floods of increasing magnitude mean existing levees may no longer be adequate. Breaches and overtopping may become more common. High cost, not reversible, long-term commitment, ‘hard’, negative externalities. Can be regarded as no regrets where used as a last resort for high value assets or key infrastructure.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
		• processes for removal of illegal levees; • strategies to minimise impacts of pseudo-levees; and • resolution of liability issues. Negative externalities: transfers damage elsewhere; reduces flood storage area (increases flood depth, velocity and erosive power); damages natural assets, visual impacts. Levees not suitable to protect farmland due to low value of protected Can impede natural drainage of floodwaters and so prolong floods. Flooding may also originate from sources the levee is not designed to prevent. Can interfere with flood intelligence (ability to predict flood behaviour).	
Sea walls, flood gates	Reduces frequency of flood damage and erosion for existing development. Particularly relevant for property subject to sea level rise and increased storm surge. Delays or prevents need to relocate. Mangroves could be considered as a low maintenance option to mitigate storm surge.	Similar cost and maintenance issues to levees. Can also have negative visual and ecological impacts. Contingency planning, retreat from high risk areas, development restrictions and conditions need to be rigorously applied to support structural measures or they could accentuate future risks.	Climate change is likely to increase the intensity (but not frequency) of cyclones in the north of Australia. Sea level rise and increased storm surge are expected to expose $226 billion of Australian coastal assets to flood damage and erosion. These measures reduce damage to existing assets and prolong their use. Avoids long term commitment (it can prolong settlement of

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
			increasingly risky areas; 'retreat' is not reversible).
Improved dam management	Processes for adjusting dam full supply levels could improve flood mitigation when major flooding is expected with a high degree of certainty. Assessments of dam capacity that incorporate climate change scenarios would help ensure infrastructure is able to manage increased inflows safely. Decision support systems, modelling and operation manuals can assist optimal timing of dam releases during and following floods to reduce damages. Communication protocols and better flood warning processes for those living directly below dams increases safety.	Where dams are managed for the conflicting objectives of water supply, hydropower generation and flood mitigation, clear triggers, responsibilities and processes are needed to manage water levels. A dam can't be empty to catch flood peaks and full to deliver water or power at the same time. A high degree of confidence in long range seasonal forecasting is needed to justify pre-release. Pre-release of water could compromise supply during drought if flooding doesn't eventuate. This could also have political fall-out. Needs careful risk assessment and community 'ownership' of processes. To optimise timing of releases during floods accurate data is needed above dams to predict inflows and models need to show high tides and peak river flows downstream. This information is sometimes lacking.	Flood events are expected to increase in frequency and severity. Dams will need to be able to safely withstand and manage increased inflows. Droughts are also expected to become increasingly severe, exacerbating the conflict between flood mitigation and water supply functions. Hydrological studies underpinning dam management and safety assessment need to incorporate climate change scenarios. No regrets, soft, flexible.
Additional flood mitigation dams	Reviews found dams mitigated peak flows during the 2010-11 floods regardless of whether they had a mitigation function.	Common perceptions that land below mitigation dams is flood proof encourages the development of that land and increases the consequences of large scale floods. (e.g., DFLs can be adjusted to incorporate the assumed mitigation effect of dams, opening a wider area up for development). Elimination of small to moderate floods by capturing all floodwaters devastates natural systems. Land use systems that can	Climate change will put natural systems under greater pressure. See also above, 'improved dam management'. High cost, not flexible and rarely decommissioned, 'hard', negative externalities.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
		accommodate smaller floods maintain the benefits of floods while minimising damages. The temptation to use empty storage for water supply during drought will be strong. Wivenhoe example reported in QLD Inquiry. Dam failure has high consequences for lives and property. Dams did not breach during 2010-11 events but the QLD Inquiry revealed safety issues.	

Planning/preparation

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
Community Resilience: awareness of risks and remedies	Can lead to shared responsibility of risks and reduced vulnerability, e.g., • purchase decisions; • mitigation investment; • planning and preparation; • insurance cover; • public support for adaptive flood measures; and • identification of opportunities.	Unavailability or lack of property-scale flood risk information. Standards need to ensure quality information in understandable formats (see National Flood Risk Information Program) Shared responsibility is not automatic when risk information is provided. It is limited by economic and social capacity and cultural attitudes. Needs on-going commitment.	Individuals and communities will need to be more self-reliant: • Large scale complex disasters that overwhelm emergency services are more likely; • Increasing numbers of costly disasters may reduce the availability of disaster relief and recovery funds. No-regrets, low cost, soft.
Community Resilience: planning and preparation	Helps populations in flood risk areas to be aware of risks, local disaster arrangements and steps needed for households to plan and	Changing behaviour is more challenging and less effective than developing away from flood risk.	If land subject to flooding expands due to climate change, the need for

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
	prepare for emergencies. Planning can reduce damages and risks to life. Can tap into existing networks, e.g., schools, community organisations, media. Existing programs, e.g., FloodSafe, have been shown to improve preparedness. Relatively low cost.	The need for this measure signals past development failures. Ongoing commitment to community education is needed: • to ensure understanding of terminology, warnings, and consistent use of terms; • to help people develop household emergency plans that ensure appropriate response; and • to support business and public continuity planning. Challenges to convince people to prepare for flood during prolonged drought.	contingency measures will also expand. Resources are stretched in large scale floods. The more severe and widespread the event, the more people in flood prone areas will need to rely on their own resources to respond and recover, which requires preparation. Climate change is likely to increase the severity of drought, reducing awareness of the need to prepare for flood. No-regrets, low cost, soft.
Improved Emergency Management Planning	Appropriate facilities, personnel, expertise, equipment and processes are more likely to be available in emergencies if they are pre-planned.	Reviews found planning for floods was compromised by: • Lack or poor quality of flood plans; • Planning that stops at administrative boundaries; • Administrative boundaries do not overlap (e.g. of different response agencies); • Varying capacity and resources to produce quality plans; • Poor oversight and approval processes for emergency plans; • No legislative requirement for some levels of planning; and	Flood planning in some localities is not adequate to address complex emergencies. Emergency management planning needs to take into account possible changes to flood patterns as a result of climate change to ensure arrangements are sufficient to address risks. No-regrets, soft. While relatively low cost, resources may be lacking.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
		• Particular deficiencies were noted for evacuation and isolation planning, contingency planning, capacity and capability assessment, volunteer planning for clean-up.	

Response

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
Improved flood information and warning systems	Warnings provide time to move people and property to safer locations. This can potentially reduce flood damage by up to 80%. Improved alignment of areas of risk with coverage of warning systems. A key element of community resilience.	Most flood maps do not contain sufficient information to be useful for emergency response (e.g., depth, velocity, range of likelihood scenarios, consequence). Type and distribution of gauges was insufficient in some areas. Councils incur ongoing maintenance obligations for data collection equipment which discourages uptake. Funding of warning systems is piecemeal leading to gaps and inconsistent standards across catchments. Governance issues were identified (e.g., need audit and oversight of warning systems; roles of BoM, state and local governments are unclear or inappropriate, leading to lack of accountability and poor service). 'Unprecedented' gauge readings can be disregarded as 'faulty', (e.g., Helidon gauge	An increasingly fluctuating climate needs to be supported by accurate and timely data to support warning systems. Every review found that flooding in some areas was 'unprecedented'. With climate change, unprecedented flooding (location or severity) is increasingly likely. Better data collection, coverage of warning systems and failsafe procedures for checking unusual readings would assist response where unexpected flooding occurs. More intense precipitation is likely to increase flash flooding, where there is a very small timeframe for collecting and processing data into flood intelligence and issuing warnings.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
		upstream from Grantham). Verification mechanisms are need. There is a trade-off between warning timeliness and accuracy. Very vulnerable to electricity supply failure. Communications systems may not havesufficient capacity to deal with large scale emergencies, e.g., websites and call centres. Flood warnings do not always elicit appropriate community action. Requires communication processes, content & terminology, pre-determined templates.	No regrets. Management and behavioural aspects are 'soft'.
Robust emergency management framework	Clear roles, responsibilities, powers, procedures and accountabilities are more effectively able to manage emergencies. This becomes more critical the more complex the event (e.g., where many different agencies are involved).	Needs to be supported by emergency policy, strategy, governance structure and legislation. E.g., Some legislation reflects out-of-date roles or does not provide required powers. Those assigned responsibilities do not always have adequate resources to carry them out. Emergency procedures need to include scale-up mechanisms and triggers.	Good management is especially important for large scale, complex flooding, which is likely to occur more often as a result of climate change. No regrets, flexible, soft.
All Agencies, All Hazards Approach, interoperability	Responders may lack sufficient resources in a large flood event to carry out designated functions: It is costly and impractical to maintain a large organisation of responders dedicated to flood when flood events might occur decades apart. Ability to pool the resources of different	Requires interoperability of communication systems, processes, regular joint agency training, IT systems and common information management portals between agencies (e.g., so requests for assistance can be prioritised and matched with supply) There can be legislative barriers to using staff from other emergency agencies. There can also	Complex emergencies, of larger magnitude, long duration, extensive areas affected, are likely to become more common with climate change. There are difficulties in supplying sufficient equipment and numbers of experienced, trained staff at all times if events are large or of long duration. The all agencies, all

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
	agencies in a large disaster improves response capacity. This approach reduces duplication and saves money (e.g., separate facilities and technologies are not required for each agency). Incompatibility of systems and processes hampers communication and causes confusion in a high pressure situation.	be liability or OH&S issues if untrained, unauthorised agencies assume control. 'All hazards' needs to be incorporated by agencies involved in risk assessment, emergency planning and development planning, equipment purchases. This approach has been an objective in Australian emergency management for over two decades but has yet to be achieved.	hazards approach improves capacity to respond to large, complex events. No regrets, flexible, soft. Cost effective as use of resources is maximized.
Evacuation and Isolation	Minimises injury and loss of life.	Evacuation and isolation planning and procedures are often inadequate or lacking. Planning is needed for evacuation trigger points, routes, facilities and support. Specific issues raised by reviews include: • facilities need to suit the hazard(s) faced (e.g., not floodable; cyclone proof) and scale of event; • arrangements needed for informal evacuation centres, especially for isolated communities; • facilities need to be suited to function (e.g. using evacuation facility criteria); • need to incorporate NGO groups in planning, communication and timing of evacuations; • identification of vulnerable groups needing evacuation assistance; and	Greater numbers of people may be displaced or isolated for longer periods of time if flooding increases in severity, extent or duration. Sea level rise will increase storm surge and good evacuation planning will be critical to the safety of some coastal communities. No regrets, flexible, soft.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
		• need to plan processing of evacuees and support services.	
Protection of essential services	Essential during emergency response for providing timely warnings and updates, provision of data for responders, communication and coordinating response.	Appropriate siting and design are the most effective ways of ensuring continued operation during floods. Essential services cannot always be sited out of harm's way (e.g., legal obligation to provide services to development regardless of where it is sited) Appropriate risk mitigation strategies are sometimes lacking. Risk assessment and business continuity planning are needed for all essential services, including community services. Protective measures need to be planned in advance, offsite impacts assessed and incorporated into broader community emergency management plans.	There is likely to be an increase in the number of large, complex flood events involving multiple agencies. The more complex the emergency, the more critical essential services are to manage it. No regrets. While physical protection is 'hard', it may be temporary and reversible (e.g., sandbags). Improved planning and management are 'soft'. Long term avoided costs (to both companies and society) but higher upfront construction / replacement costs.
Improving the arrangements for response volunteers	Increases the number of people available to help in emergencies at minimal on-going cost.	If using volunteers, aspects such as liability, training, coordination and supervision need to be addressed. Legislative support may be needed (e.g., in VIC there are legislative barriers for SES volunteers to exercise control functions). Volunteers in some areas are under resourced (e.g., some QLD SES units fund raise 40% of their operating budgets).	The number of personnel required during a complex emergency is enormous and outside routine operational capacity. Resources will be stretched, especially if severe events become more frequent. No regrets, low cost, flexible, soft.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
		Incorporation of volunteers into response and recovery requires good planning and flexible staffing arrangements There are limits to volunteer capacity to engage (e.g., competing demands on time for acquiring competencies). Response agencies compete for the same volunteer pool (e.g., SES and fire services).	

Recovery

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
Insurance for flood	Primary means for businesses and individuals to finance recovery. Reduces the need for disaster relief. Premium pricing can raise awareness about level of risk. This can encourage people to consider mitigation, especially if pricing offers incentives to do so. Those incurring the risk pay the costs associated with it instead of relying on others to do so. The USA national flood insurance program has introduced many elements to improve future flood resilience. E.g., supplementary insurance to enable rebuilding to a better standard. Rapid recovery is the most successful. Area hydrology reports rather than site specific reports were found effective to speed up the assessment process (where cause of flooding needs to be established).	Insurance creates a potential moral hazard by insulating people from the financial consequences of settling in risky areas. In areas of high risk, insurance may be unavailable or unaffordable, compromising ability to recover. Many of those who live in flood prone areas (e.g. semi-industrial or rural) are poor and unable to afford high insurance premiums. Living elsewhere may not be a choice. They also have fewer savings to recover. Such people are highly vulnerable to climate change. Cultural and social influences may prevent uptake e.g., gambling on the (un)likelihood of a flood; perception of government responsibility for disasters. Uncertainty and the need to be competitive prevent climate change from being factored into risks and pricing: risks may be underestimated. Insurance pay outs are only sufficient to repair damage, not rebuilding to improved standard or relocation. Where insurers offer incentives to mitigate, they need to be careful to promote adaptive solutions and alternatives.	An IPCC paper suggests a doubling of CO_2 will increase flood damages between four and ten-fold in three Australian drainage basins (Bates et al. 2008). If severe disasters occur more regularly, or in areas not built to resist flood, insurers can expect ever increasing damage costs. The more widespread and severe the event, the less capacity the insurance industry has to rapidly assess damage, which can delay clean up and recovery. Climate change risks are more likely to be factored into pricing if they are included in local flood studies. Those already vulnerable will be impacted most heavily as they have limited capacity to recover. This challenges the wisdom of affordable housing policies that don't consider flood risk, long term losses and psychological impacts. No regrets, flexible, soft.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
Processes to ensure rapid and enduring recovery	Rapid clean up reduces indirect costs (e.g., downtime for business, spoilage, costs of temporary accommodation, stress). Volunteers greatly improve capacity to recover following a large disaster. Upfront funding for local governments of 50% of expected disaster costs via trust fund was successful in helping speedy recovery.	Processes to identify people needing assistance can be inefficient, (e.g., misperceptions about privacy laws resulting in the provision of the same information to multiple agencies; lack of clarity about agency roles leading to duplication and omissions). Needs good planning, systems, use of protocols. In large disasters insufficient capacity prevents rapid assessment and repairs. Speed and effectiveness of recovery programs and deployment of Community Development Officers vary from state to state and between disasters. These are needed as early as possible. Recovery grant and reimbursement claim processes are complex and inclusions sometimes unclear or misunderstood. Currently grants schemes do not increase the disaster resilience of rebuilds and generous provisions have the potential to act as a disincentive to responsible land planning (see prevention section). Grants to individuals are badly targeted and too small to help those worst affected. Hasty recovery can ensure continued exposure to risks and lack of planning controls facilitates this in some areas, e.g., the Brisbane Review noted rebuilds or repairs do not have to comply	An IPCC paper suggests a doubling of CO_2 will increase flood damages between four and ten-fold in three Australian drainage basins (Bates et al. 2008). If severe disasters occur more regularly, or in areas not built to resist flood, insurers can expect ever increasing damage costs. The more widespread and severe the event, the less capacity the insurance industry has to rapidly assess damage, which can delay clean up and recovery. Climate change risks are more likely to be factored into pricing if they are included in local flood studies. Those already vulnerable will be impacted most heavily as they have limited capacity to recover. This challenges the wisdom of affordable housing policies that don't consider flood risk, long term losses and psychological impacts. No regrets, flexible, soft.

Measure	Benefits	Disadvantages/existing barriers	In a changing climate
		with improved standards and are not subject to approval. Use of volunteers in initial clean up (e.g. ~50,000 in Brisbane) needs good planning and liability issues need to be resolved. Where coordination is bad, volunteers can be a hindrance.	

Appendix 5: Conference paper delivered to the 54th Floodplain Management Association Conference, Deniliquin, 2014

The NCCARF case study (publication 3 of the thesis) was prepared during a period of rapid change in emergency management arrangements and legislation following 2010-11 floods across eastern Australian and repeat flooding in the years that followed. It was written as a 'snapshot in time', throwing light on the types of arrangements and measures in place that might have contributed to the disaster. The conference paper, below, was intended to communicate this work but it also covers some administrative and legislative changes that happened in the aftermath of the floods. The conference paper and presentation slides are available on the Floodplain Management Association's website at:

> http://www.floodplainconference.com/presentations2014/Caroline%20Wenger.pdf
> http://www.floodplainconference.com/papers2014/Caroline%20Wenger%20full%20paper.pdf

Climate change adaptation and flooding: Australia's statutory and institutional arrangements

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1. Introduction

Flooding is Australia's most expensive natural hazard and 2010-2011 saw some of the biggest flood events in Australia's history. The Federal Government allocated $5.6 billion in recovery funding to Queensland and almost $1 billion to Victoria, primarily to restore public infrastructure (Gillard 2011; VAGO 2013). Climate change scenarios predict increasing intensity and frequency of floods, potentially exposing Australia to even greater damages in the future. Flood management is thus a key area for improving adaptive capacity.

Past research identified inadequacies in institutional and regulatory arrangements, development planning and funding mechanisms (Wenger *et al.* 2013). It pointed overwhelmingly to the need for improvements in non-structural measures, particularly in the preventative phase of emergency management. It also found that successful and cost-effective approaches to flooding overseas are largely unknown in Australia, and would have difficulty being implemented under current arrangements.

Accordingly, this paper explores flooding from the perspective of government function. Current policies and institutional arrangements are explored and assessed for their ability to address climate change threats. Reforms are also suggested to reduce Australia's future vulnerability to flood.

2. Methodology

This research was undertaken as part of a broader project, *Statutory frameworks, institutions and policy processes for climate adaptation,* funded by the National Climate Change Adaptation Research Facility (Hussey *et al.* 2013) and formed one of the project's seven case studies (Wenger 2013).

Research was based on literature review. Due to the nature of the topic, government documents formed a large proportion of source material, including flood reviews, policy documents, agreements and funding reports. The report also drew on work the author carried out for NCCARF project, *Living with floods: key lessons from Australia and abroad* (Wenger *et al.* 2013). Flooding was analysed in terms of seven institutional mechanisms, namely intergovernmental function; intra-governmental function; regulation by prescription; planning processes; funding mechanisms; information and analysis; and supporting market arrangements. These were selected by the project team as being instruments that governments can use to stimulate adaptation to climate change (Hussey *et al*. 2013).

Past research suggests that in terms of avoided damages, prevention is highly cost effective (BTRE 2002; Healy and Malhotra 2009). Moreover, non-structural methods of prevention such as land use planning and building standards are more effective than attempting to modify human response behaviour through public education, warning systems and emergency response (Comrie 2011). The paper therefore focuses on identifying the drivers and barriers influencing the adoption of proactive prevention and mitigation approaches to flood management.

The scope of the original case study was limited to institutional arrangements in place at the time of the 2010-11 floods. This paper incorporates some recent changes.

3. Findings

3.1 Intergovernmental function

Under Australia's constitution state governments have primary responsibility for natural resources and, by extension, flood management. State and territory governments develop policy, strategies, tools and legislation, and devolve much of the responsibility for implementation to local government. States may also directly approve development, especially where projects have regional or state-wide significance. Federal government involvement generally takes the form of exhortative and cooperative styled policy instruments such as intergovernmental agreements, and the provision of funding, information, standards and guidelines.

In recent times, disaster management has focused on resilience, a broad term that covers all aspects of disaster management, including prevention/mitigation, preparation, response and recovery (PPRR). It can be applied to communities, management systems and infrastructure. This moves away from 'mitigation', which became the program focus following a report to COAG on flood mitigation (DOTARS 2004).

Currently, the most influential intergovernmental mechanism for emergency management is the National Strategy for Disaster Resilience (NSDR), formally adopted by COAG in February 2011. The NSDR attempts to drive a cooperative, national approach to natural disaster management. The strategy is broad in scope, covering leadership, risk assessment, empowerment, awareness, partnerships, prevention and response capacity. Future drivers such as climate change and development pressure are provided as the rationale for developing the strategy (COAG 2011).

Other intergovernmental mechanisms applicable to flooding and adaptation to climate were studied (Australian Government 2009; COAG 2007; MCPEM-EM 2009; AEMI 2012; ABCB 2012). Analysis found that implementation of some of these, including the Climate Change Adaptation Action Plan was patchy, while at the time of the 2010-11 floods, Australian Building Code Board had no standards that addressed flooding (Wenger 2013).

Nevertheless, mechanisms are comprehensive in that they seek to address knowledge gaps about climate change related flooding, and to integrate this knowledge into planning, professional training and awareness raising. Strategies incorporate measures known to reduce exposure to flooding, such as improved development planning. Whether or not these mechanisms will translate to improved management on the ground remains doubtful. Other sections of this paper reveal many barriers, including the non-mandatory nature of many provisions relating to flooding, disincentives such as badly targeted flood relief, conflicting development policy objectives, planning tools that are inadequate to address future risks and inadequate resourcing.

3.2 Intra-governmental function

Intra-governmental mechanisms for flood operate at all levels of government. These collaborations are important in ensuring a whole of government approach and are often highly efficient in making use of skills and resources from other agencies, pooling financial resources, and providing a focus for common concerns that might otherwise be overlooked due to competing priorities. This is particularly the case for many local government alliances such as the Sydney Coastal Councils Group (SCCG 2012*a*; SCCG 2012*b*). SCCG has effectively advocated the retention of strong climate change planning laws, has information exchange processes, and has formed partnerships with research institutions such as CSIRO to increase information relating to climate change adaptation. Ten such alliances cover most of Victoria (NAGA and SECCCA 2012).

At the federal government level, collaborative efforts have been established to implement the NSDR. The national flood risk information project (NFRIP), aiming to increase the availability of flood information, involves the Bureau of Meteorology, Geoscience Australia and Emergency Management Australia (Geoscience Australia 2012).

Intra-government mechanisms are not always effective, however and significant issues were identified by the Queensland Floods Commission of Inquiry (QFCI) surrounding the application of flood controls in that state.

Arrangements to manage development in floodprone areas can involve interactions between multiple state departments. At the time of the 2010-11 floods, State Planning Policy 1/03 (SPP1/03) was the most important state planning instrument for considering flood risk in Queensland and was administered by the Department of Community Safety (DCS). The Department of Environment and Resource Management had an advisory role and the Minister for Local Government and Planning was responsible for approving planning schemes. The Inquiry found that recommendations by DCS to ensure compliance with SPP1/03, including sufficient flood mapping and nomination of a defined flood event, were routinely disregarded by the Department of Local Government and Planning, resulting in floodprone communities, including Brisbane and Emerald, having non-compliant planning schemes. This raised serious questions about administrative procedures and accountability measures. Queensland State Government departments have since been restructured and the Department of State Development, Infrastructure and Planning is responsible for both SPP administration and planning schemes.

Conflicting policy objectives that pit short term economic gains against long term damage costs are likely to be a root cause in the failure of the Queensland approvals process. Many policy conflicts are directly or indirectly related to upfront development costs and housing affordability. The provision of cheap (but risky) residential sites to disadvantaged groups who can't afford premium, flood-free land only increases their long term vulnerability to climate change. This is not consistent with the 'community resilience' approach. Neither is it a just solution in terms of the impacts people will be exposed to.

State and local governments are responsible for providing affordable housing, and yet it is the Federal Government that provides the majority of relief and recovery funding. Unless the financial liabilities for bad development decisions rest with those making them, there will be little incentive to change.

3.3 Regulation by prescription

State planning legislation

Development planning is a key measure for flood prevention. However, prevention of development in floodprone areas has proved difficult to achieve.

The Queensland Planning Provisions (revised October 2013) are developed under the Sustainable Planning Act 2009 (Qld) and flood hazard is included in its standard suite of overlays. At the time of the 2010-11 floods, the overlay was optional, even where flood mapping information was available (QFCI 2012). Section 8.1 of the current version lists specific circumstances where application of an overlay is now a minimum requirement (Queensland Government, 2013).

Where provisions are mandatory, they may have conditional application, for example, they depend on the existence of flood mapping to identify floodprone areas and may also require the adoption of a defined flood event. This was a serious issue for the application of Queensland's recently expired SPP1/03 and Victoria's Planning Provisions (QFCI 2012; Comrie 2011).

Queensland replaced SPP1/03 and other state planning policies with a single state planning policy in December 2013 (DSDIP 2013b). Provisions in the policy are general, but are supported by guidelines (in draft) (DSDIP 2013a). Sustainable Planning Act 2009 (s117(1); s119; s130) requires that local governments follow guideline processes.

Application of planning legislation and instruments to address flood can be significantly compromised by exemptions. The QFCI examined many examples where development was exempt from applying SPP1/03 (QFCI, 2012, pp. 91, 98, 108, 149, 153, 156, 166, 169, 175, 190-193, 197, 242-244). Another concern was that satellite planning schemes did not have to comply with SPP1/03, among them, a scheme designed to expedite approval of development applications for affordable housing (QFCI 2012).

State legislation relating to land-use planning sometimes requires sea level rise to be taken into account (Gibbs and Hill, 2011) but most states give little consideration to the effect changes in rainfall patterns will have on inland flooding. In Queensland, draft state planning policy guidelines require 'climate variability' to be incorporated into flood studies using the Australian Rainfall and Runoff Guidelines (currently under revision) and climate change factors developed by its inland flood review (State of Queensland 2010; DSDIP 2013a).

The Federal government role

Under constitutional arrangements, the Federal Government has little ability to legislate on planning issues and it has adopted a leadership and coordination role through intergovernmental agreements.

Overseas experience suggests it could be possible for the Federal Government to expand its influence should it wish to do so. The USA Federal Government is similarly constrained but has implemented legislative measures that encourage improved land use and development controls. The USA's Flood Disaster Protection Act 1973 prohibits federal agencies from providing communities with assistance in floodplain acquisition or construction unless communities participate in the national flood insurance program. This program (as well as requiring mandatory insurance), imposes minimum land use and control requirements for new construction in floodprone areas. The Act's provisions also apply to "financial institutions regulated or insured by the Federal Government, thereby covering virtually all types of financial assistance" (Wright 2000). While national flood insurance is unlikely to be an approach suitable for Australia, it demonstrates that there are options for the Federal Government to apply legislative and financial incentives to reduce future disaster relief and recovery bills.

Building codes and standards

National building standards are set through the Building Code of Australia. These are minimum standards and states may enact more rigorous standards. At the time of the 2010-11 floods there were no national standards for building in floodprone areas. The Australian Building Codes Board has since developed a standard for residential development (ABCB 2012). The standard uses definitions such as 'defined flood event' that rely on historic flood levels. The standard makes no reference to climate change.

The accompanying Information Handbook references climate change in its introduction but the purpose of the document is 'not mandatory or regulatory in nature' and it is questionable whether it will have much influence ensuring climate change is incorporated into key local planning tools.

Catchment management authorities (CMAs) and the development approval process

Under Victoria's Planning and Environment Act 1987, if land is within a flood zone or overlay, planning permits have to be referred to the relevant CMA. In 2013, the State Government substantially weakened CMA powers, changing them from designated determining referral authorities to designated recommending referral authorities (DTPLI 2013). Prior to this, CMAs had the power to veto or impose conditions on inappropriate development. The Comrie Review recommended that CMAs retain their powers in the development approvals process as they have technical expertise in flood management and a long term understanding of flood risk implications (Comrie 2011). In NSW, CMA legislation has also been weakened. The Catchment Management Authorities Act (2003) was repealed in January 2014 and CMAs were amalgamated with other agencies into new Local Land Services agencies. Catchment boundaries were redrawn to reflect production areas and local government boundaries (NSW Government 2013). This is unfortunate as CMAs have a long term perspective that is particularly relevant to adapting to future flood scenarios.

3.4 Planning processes

The adequacy of planning tools to accommodate climate change

There are significant barriers to incorporating up-dated information into planning schemes in both Victoria and Queensland, including a ten-year interval before some planning instruments become due for revision. This is likely to be a serious impediment to the incorporation of climate change information into planning schemes (Wenger 2013).

Adoption of a Defined Flood Event (DFE) or Flood Level is a key planning tool in both Queensland and Victoria. Generally a 1:100 year event is selected for residential areas (QFCI 2012:147; Comrie 2011).

The accuracy of flood mapping is a significant problem. Uncertainties regarding Brisbane's 1:100 year floodline were identified by the QFCI, with past estimates ranging from 3.16 m to 5.34 m at the city gauge (QFCI 2012; QFCI 2011). Recent studies suggest that the use of the 1:100 year event standard for flood control may be inadequate. Whether due to inaccurate data, climate change or urbanisation, the 1:100 floodline is not static but can move. What was once a 1:100 year event is likely to become a more frequent occurrence. This can place people at unacceptable risk of flooding (Wenger *et al*. 2012; Hirabayashi *et al*. 2013; Pedruco and Watkinson 2010; Freitag *et al*. 2009).

According to the Bureau of Transport and Regional Economics, the difference between a 100-year flood level and the probable maximum flood can be measured in centimetres for most NSW floodplains (BTRE, 2002). Thus, adapting to higher flood frequencies may only require minimal adjustments - for example, of floor height requirements - in many areas of Australia.

There has been debate about the acceptability of lower habitable floor levels for residential areas, for example, at the 1:50 year flood level, depending on the community's willingness to accept risk (QFCI 2012). Queensland's new state planning policy guidelines allow this option (DSDIP 2013a). This raises the question of who will bear the cost of that risk: the communities themselves, insurance companies, charities, taxpayers or future generations. A recent decision by Suncorp to not insure entire towns for flood risk unless mitigation measures are undertaken indicates that insurance companies, at least, are not willing to bear the cost (Milliard 2012). As flood hazard is likely to increase, accepting lower control standards appears maladaptive.

Ecosystem approaches to flood management

Some of the most expensive flood damage is caused by water velocity. This affects infrastructure such as roads, bridges and railways, erodes farmland, reduces water quality and decreases the storage capacity of dams due to siltation (Parliament of Victoria 2012; Rutherfurd *et al*. 2007; Wenger *et al*. 2013).

In countries such as the Netherlands and China this is addressed through improved land management. 'Room for the river' initiatives, involving wetland restoration, relocation, levee removal or setback and flood-compatible land use increase the floodable area, reducing flood depth and velocity. Often these changes are associated with multiple economic, social, environmental and health benefits (Wenger *et al*. 2013).

Ecosystems approaches rely strongly on a catchment-wide management. Improving flood retention in upper catchments (where land value is generally lower) delays downstream flooding, increases warning times, potentially reduces damage and casualties from flash flooding. It also reduces flood peaks, and crucially, decreases the power of floodwaters in the middle and lower catchments. Another benefit is that water retention allows aquifer recharge, a significant benefit that could help address increasing severity of climate change drought. Suitable interventions in productive middle catchments include bank stabilisation with riparian vegetation.

Ecosystem approaches to flood mitigation are probably the least understood in Australia. One of the biggest challenges is that they require implementation on a catchment scale. Local council responsibilities stop at municipal boundaries and achieving a catchment approach to flood management is beyond the capacity of most councils. Segregation between traditional flood management and natural resource management disciplines and lack of community understanding about hydrology also constitute significant barriers (Parliament of Victoria 2012; see also interviews, Wenger *et al*. 2013).

CMAs appear well placed to implement ecosystem approaches to flood control, and in some states such as Victoria have been doing so for many years through their management of riparian vegetation. However programs of similar scope and complexity to those overseas would require adequate resourcing and authority.

Promisingly, Queensland's new SPP recognises the role of natural assets in flood regulation and requires planning schemes to include provisions for development to 'maintain and enhance natural processes and the protective function of landforms and vegetation that can mitigate the risks associated with the natural hazard' (DSDIP, 2013b). However, the same document supports the use of mitigation infrastructure, which commonly undermines natural flood mitigation (Freitag *et al*. 2009; Tockner *et al*. 2008).

3.5 Funding mechanisms

National partnership agreement on natural disaster resilience

The Natural Disaster Resilience Grants Scheme, administered under the National Partnership Agreement on Natural Disaster Resilience, currently under revision, is the primary funding mechanism that supports disaster prevention in Australia. The amount allocated by the Federal Government to this agreement (2009-10 to 2012-13) was approximately $100 million, to be divided between all the states and territories (COAG 2009). An additional $3.6 million per year is allocated through National Emergency Management Projects (AGD, nd). Combined, these funding mechanisms provide approximately $28.7 million per annum of federal money to natural disaster resilience.

The National Partnership Agreement is extremely broad. Funding is divided between all states and territories, and between all natural hazards. The Agreement defines resilience as "the capacity to prevent/mitigate, prepare for, respond to and recover from the impacts of disasters". Thus the funding may also be divided between all phases of PPRR. A disadvantage of this breadth of coverage is that limited funds are thinly spread. Australia's flood damages (1967-2005) averaged $377 million per year (BITRE 2008) and state and federal reconstruction costs following the 2010-11 floods were close to $10 billion (Wenger 2013). In this context, annual allocation of $30 million by the Federal Government towards disaster resilience appears grossly insufficient.

The Partnership Agreement is touted as addressing climate change adaptation on websites and in annual reports (AGD 2010; AGD 2013). However, the Partnership Agreement itself makes no mention of climate change and a study of the eight implementation plans for 2011-12 found that six made no reference to climate change. Lack of detail makes it hard to gauge the level to which climate change is integrated.

Natural disaster relief and recovery arrangements (NDRRA)

Disaster recovery is primarily funded through the NDRRA grants process, activated when financial thresholds for disaster costs are exceeded. For large disasters, the Federal Government shares disaster costs with state governments.

Commonwealth expenditure on public infrastructure reconstruction following the 2010-11 floods was around $6.6 billion. This represents three quarters of the total expense funded through the NDRRA, with the balance funded by state governments (AGD 2011). For a country with a relatively small population, this is a significant cost. In order to fund this enormous recovery bill, the Commonwealth government implemented an additional tax levy on Australian income earners (not applicable to those living in flood affected areas). It also reduced or discontinued spending to numerous Commonwealth government programs. Ironically, most of the programs sacrificed were designed to mitigate climate change (Gillard 2011).

Many have noted that disaster relief and recovery funding can have the perverse effect of removing the incentive to invest in prevention. While accepting the benefits of occupying floodplains, the costs of occupying that land are externalised to federal governments and taxpayers (ASFPM 2007; Larson 2009; Wright 2000).

While recovery is generally not viewed as being 'prevention', it can become so. The 1993 floods in the upper Mississippi caused a major shift in disaster relief in the United States resulting in a "consensus that rebuilding or restoring to pre-flood conditions was not an acceptable policy position". Recovery and mitigation became increasingly integrated in the United States and for some disasters they completely merged (Wright 2000). Analyses of avoided flood damages indicate that US investment in preventative recovery, particularly relocation, have saved billions of dollars in avoided damages (Freitag *et al*. 2009; NWF 1998). Similarly, avoided damage at Grantham, Queensland, in 2013 more than covered the cost of its relocation (LVRC 2013).

The NSDR includes among its priority outcomes:

> Following a disaster, the appropriateness of rebuilding in the same location, or rebuilding to a more resilient standard to reduce future risks, is adequately considered by authorities and individuals
>
> (COAG 2011)

However, disaster mitigation is not currently integrated into Australia's disaster relief other than for public assets. While there were isolated examples of relocation following the 2010-11 floods at Grantham, and the Lower Loddon, Victoria, relocation is not a consistent policy. COAG's objective seems far from being realised.

In Australia, prevention is integrated into recovery (for public assets) through 'betterment' provisions, or rebuilding to improved standards. While technically allowed by the NDRRA, no betterment projects had ever been approved by the Commonwealth at the time of the 2010-11 floods (Comrie 2011). A once-off betterment fund has since been created for Queensland, and eighteen infrastructure projects have received approval (Gillard 2013; QRA 2014). However, the Victorian Auditor-General's Office reported none of Victoria's 23 proposed betterment projects had been approved as at the end of the 2012-13 financial year (VAGO 2013).

Difficulties in achieving betterment include the speed with which recovery measures need to be implemented following a disaster and the time required to assess options (Wright 2000; Wenger *et al*. 2013). In the United States, this is overcome by a statutory provision that 15% of federal disaster costs be available for preventative recovery. Assessment is based on cumulative damages as a proportion of property value (FEMA 2010).

3.6 Information and analysis

Information on climate change related flooding is abundant, albeit with an emphasis on coastal flooding due to sea level rise. Accurate flood information is a prerequisite for the application of planning legislation and instruments that address flood. It also enables risk assessment and implementation of mitigation measures. However, reviews following the 2010-11 floods found that local flood information is often lacking, is not publically available or is not used. In Victoria, 80% of floodplains were mapped for a 1:100 year event but only 70% of these mapped areas were incorporated in planning schemes (Comrie 2011). In Queensland, most towns and cities are built on floodplains. However, a recent review of planning schemes found that only 37% of schemes contained any flood related mapping. Of these, only 23.6% were completed in accordance with the SPP1/03 Guideline (QFCI 2012). Since this time, both states have invested in flood mapping, including large scale mapping for all Queensland floodplains (QRA 2011; Walsh 2011).

Lack of financial and/or technical resources are a significant barrier to undertaking flood studies, flood mapping and risk assessment and there are also issues with the accuracy, completeness and currency of flood information where there is no requirement for periodic update. Flood studies are often limited to mapping the 1:100 year events. Recent flood reviews suggest this is not sufficient and events of both greater and lower likelihood need to be included, up to probable maximum flood (Comrie 2011; QFCI 2012). These recommendations are relevant to the consideration of climate change scenarios and emergency response. Recent flood mapping funded by the Victorian government includes multiple flood levels and Queensland's new SPP Guidelines also recommend identification of a range of flood events (Comrie 2011; DSDIP 2013a).

A further issue is that municipal boundaries do not coincide with catchment boundaries, resulting in local-scale flood studies. Better management outcomes can be achieved where local flood studies 'nest' within an overall catchment study and large-scale Queensland Reconstruction Authority (QRA) maps may help to address this (Wenger *et al*. 2013).

The QRA maps draw on multiple sources, including soil type, to identify areas that have inundated at some point in the past, adjusted using current contour information (QFCI 2012;

QRA 2011). The use of geological record to provide insight into flood behaviour is useful for countries like Australia, where "short historical records may give a false impression of the nature of the flood hazard for a region" (Nott 2006). Understanding past extreme flooding events and locations of ancient watercourses could improve perceptions of potential risks and reduce vulnerability to 'unprecedented' floods likely under climate change.

Awareness of flood risk is often seen as a key factor to increase community resilience, enabling shared responsibility. Problems associated with the provision of information include impacts on land values and insurance prices, intellectual property and liability for incorrect information. Geoscience Australia is currently implementing a national flood risk information project, which includes a national database for flood studies. Thus increased availability of flood risk information is the direction Australia is headed regardless of current barriers. While public awareness of flood risk is important to support community resilience, it has limitations. There are socio-economic implications in that even if risks are widely known, disadvantaged people may not be able to afford the higher purchase price of living in areas with low flood risk. They also have less financial capacity to retrofit or build using flood resistant design. Risk awareness is no substitute for good planning and development controls.

Incorporation of future threats into flood information

The need to downscale climate change flood information to catchment level has been identified as a key issue to make information locally relevant and decrease uncertainty (Milly *et al*. 2008; Productivity Commission 2012). National and state initiatives aim to address this (State of Queensland 2010; Wong 2008). However, some suggest that improved modelling is unlikely to yield the degree of certainty that planners require. For example, perception of liability can be a significant barrier to the provision of flood risk information and its incorporation into planning schemes. This is particularly the case for climate change information due to difficulty justifying decisions in the absence of certainty (Comrie 2011; QFCI 2012; Trowbridge *et al*. 2011). Hallegatte (2009) argues that decision making frameworks need to be changed to accommodate this uncertainty and he proposes a ranking system to assess adaptation options.

Councils may be liable for losses if they provide flood advice, act or fail to act in respect to flood-prone land (QFCI 2012). Potentially, councils could also be liable for failure to take climate change risks into account (Gibbs and Hill 2011; Godden and Kung 2011). Queensland's Sustainable Planning Act 2009, s706(1)(i) allows compensation exempt changes to planning schemes due to flood risk but wording has been criticised as open to interpretation (Queensland Government 2014; PIA 2013). Statutory immunity is provided by section 733 of the Local Government Act 1993 (NSW), recently amended to include climate change information.

3.7 Market mechanisms

Market based mechanisms can help to achieve improved flood mitigation, including provision of flood risk information to potential property purchasers, insurance incentives and payment for services. For example, in NSW S149 certificates contain information on development restrictions and conveyance legislation requires them to be attached to land sale contracts.

Insurance pricing can increase awareness of flood risks attached to a property. Insurers are also able to offer incentives to property owners, and even whole communities, to mitigate flood risks through offering lower premiums. New products could also facilitate adaption to flooding. In the USA for example, flood insurance offers supplementary payouts to enable an improved standard of repair in return for an additional premium (Wright 2000; IFMRC 1994).

Payment for ecological services has great potential to fund catchment-scale approaches, providing compensation for property owners who allow their land to flood, reducing impacts for people downstream. Such 'flood mitigation' businesses could diversify farm income sources as well as providing public benefits. This requires a catchment approach to flood management as measures generally need to be implemented in upper catchments, while benefits are found in middle and lower catchments, and payments would need to be transferred accordingly. Pricing would need to be adequate to provide incentive for participation. Examples of such schemes in Australia include a Moreton Bay catchment proposal to reduce erosion and sediment and Victoria's 'Trust for Nature' that funds landholders to restore and protect land through biodiversity offset agreements (QCC 2012; Trust for Nature 2012).

4. Conclusion

The current approach to flood management in Australia is 'resilience' and through federal leadership and funding, it attempts to promote shared responsibility for disasters. It is yet to be seen whether the community will accept this responsibility (and remember it during periods of prolonged drought). However, given that flooding is expected to worsen, greater self-sufficiency is a sensible adaptation if it can be achieved.

Perhaps the most significant aspect of Australia's resilience approach is the greater availability of flood risk information. While funding is limited, it has enabled the development of risk assessments and adaptation plans, as well as community awareness raising and development or revision of key flood management tools. This could prove to be a major step forward in awareness of flood risk and the need to mitigate. Other NSDR initiatives, such as the Enhancing Disaster Resilience in the Built Environment Roadmap, are innovative and hold promise. However, major opportunities to incorporate climate change risks into planning controls through the Building Code of Australia have been missed.

Drawbacks of the resilience approach include the lack of clarity about what 'resilience' means in terms of implementing the most sustainable and adaptive on-the-ground measures. Socio-economic aspects are also problematic in that many who live in floodprone areas are disadvantaged and less able to afford measures that would reduce their susceptibility.

There are significant impediments to achieving improved flood management. These include conflicting development policy objectives, many of which value short term development gains over long term disaster prevention; the non-mandatory nature of many current provisions relating to flooding; disincentives such as lack of financial consequences for those making risky development decisions; and planning that is based on administrative boundaries rather than natural geographic ones.

In order to achieve improved flood management, reforms are needed at all three levels of government. Analysis suggests that areas most in need of reform include consistent policy, legislation and planning processes to ensure that future flood risks are assessed and addressed; adequate resourcing of local governments; improved support for flood mitigation/prevention; improved public and private betterment mechanisms; administrative structures enabling a catchment based approach to flood management; training and education programs to support ecosystems approaches; and better incorporation of climate change scenarios into planning tools. With regards prevention measures, basic flood mapping is needed nation-wide, as well as improved incorporation of flood risk into development planning, relocation of those most at risk and support for ecosystems approaches. Better incorporation of climate change threats can be achieved where floodprone land (up to probable maximum flood) is identified; where decision-making relies less on information certainty and where planning tools incorporate climate threats (including building codes and processes to facilitate planning scheme updates).

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