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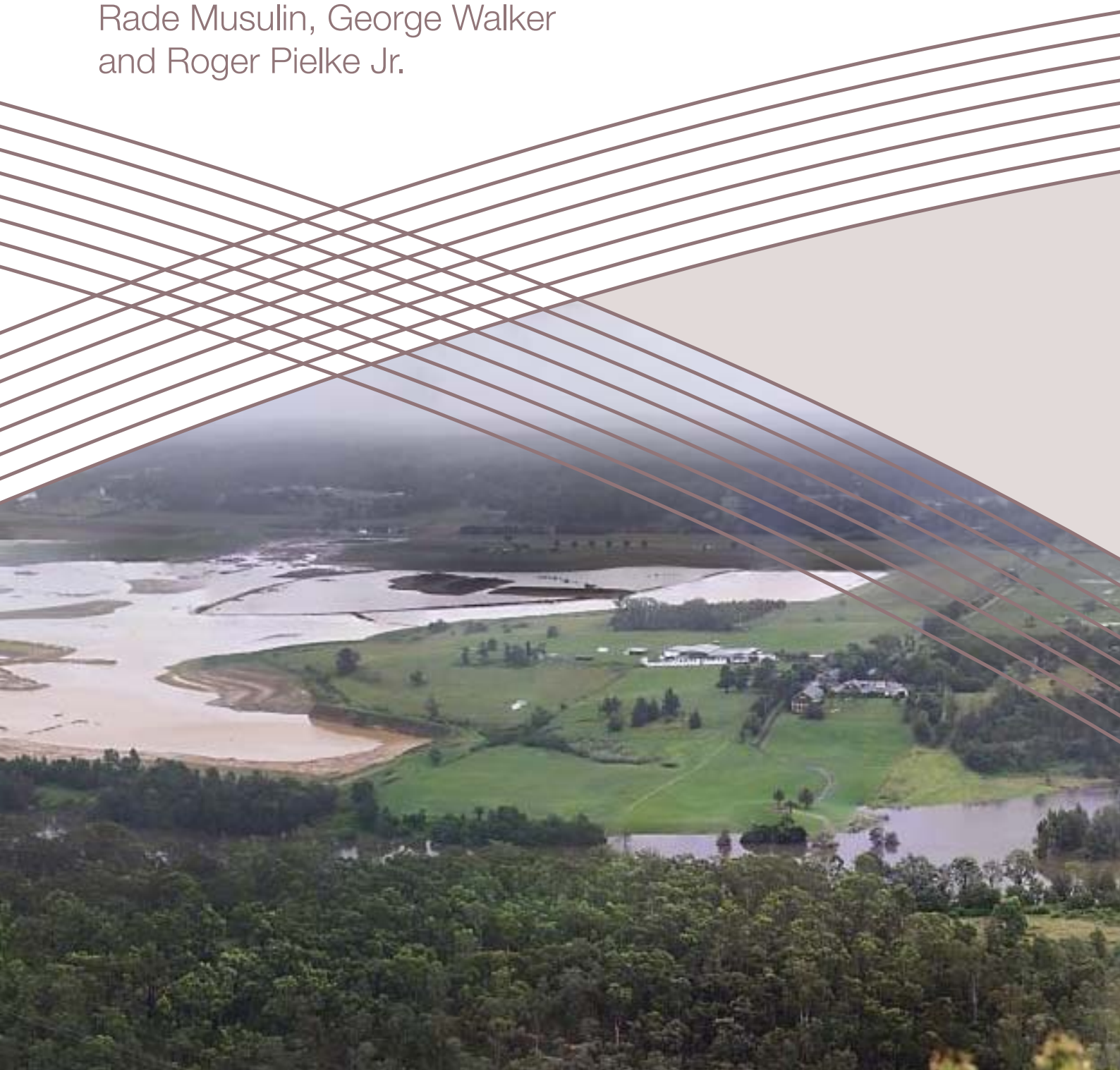Climate Change Adaptation
Research Facility

Market-based mechanisms for climate change adaptation

Final Report

John McAneney, Ryan Crompton, Delphine McAneney,
Rade Musulin, George Walker
and Roger Pielke Jr.

MARKET-BASED MECHANISMS FOR CLIMATE CHANGE ADAPTATION

Assessing the potential for and limits to insurance and market-based mechanisms for encouraging climate change adaptation

AUTHORS
John McAneney (Risk Frontiers, Macquarie University)
Ryan Crompton (Risk Frontiers, Macquarie University)
Delphine McAneney (Risk Frontiers, Macquarie University)
Rade Musulin (Aon Benfield Analytics Asia Pacific)
George Walker (Aon Benfield Analytics Asia Pacific)
Roger Pielke Jr. (University of Colorado, Boulder, USA)

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ABSTRACT

The economic and insured costs of natural disasters due to extreme weather – tropical cyclones, floods, bushfires and storms – are rising in concert with growing concentrations of population and wealth in disaster-prone regions. A contribution to these rising costs has not yet been attributed to anthropogenic climate change, although such a contribution cannot be ruled out. This finding is in accord with the IPCC report (2012).

Extreme events are, by definition, rare, and so detecting a signal of climate change in volatile time series of economic losses faces a challenging signal-to-noise problem. This situation is unlikely to change any time soon and so, in the absence of scientific clarity, decision-making in relation to climate change adaptation to extreme weather events of the types considered here, will of necessity take place in an 'environment' of uncertainty and ignorance. This reality strengthens the case for expanding disaster risk reduction as part of any climate change adaptation policy.

Given the rising cost of natural disasters, we also reviewed the provision of insurance by the public sector in a number of countries and the role they might play in encouraging risk reduction and resilience building. Examples of these *residual market mechanisms* (RMM) were drawn mainly from the US, Spain, France and New Zealand. RMM structures vary between countries as does the hazard profile: government involvement in catastrophe insurance in the US, for example, has usually arisen in the face of perceived failures of the private insurance market, often following a significant natural disaster. In the wake of such events, RRM have assumed the legacy of inappropriate land use, unrealistic risk assessment and lack of consideration to mitigation.

In undertaking this review of residual market mechanisms, we expected to identify preferred approaches or elements of the various schemes that might profitably be employed to incentivise behavioural change, at least in respect of extant risks. However none of the schemes examined could truly be said to be successful in this regard and many have led to perverse outcomes. Other key observations include the following:
  (a) transferring risk to the public purse does not reduce risk
  (b) governments can spread the cost of losses across time rather than space
  (c) governments can force home-owners in low risk areas to cross-subsidize the insurance premiums of those in high risk areas
  (d) cross-subsidisation is increasingly difficult for private sector insurers operating in a competitive market, and
  (e) governments can tax people to pay for tomorrow's disaster.

The equity of (b), (c) and (e) needs careful reflection by policy makers.

Given that the typical duration of an insurance policy is 12-months, pricing will not reflect any future changes in risk that may arise due to increasing exposure concentration or anthropogenic climate change affects on severe weather. This being the case, the best insurers can do is to provide incentives to reduce vulnerability by sending price signals on an annual basis reflecting the *extant* risk. To the extent that this were to overcome what might be called the *adaptation-deficit*, that is the degree to which society is mal-adapted to cope with current climate variability, this would also have long term benefits in respect to any additional risks posed by a warming climate.

Notwithstanding the above, some insurance companies already encourage climate change adaptation by underwriting green projects, undertaking research and generally engaging in policy debate on climate change issues. We expect this to continue. However it is not the key objective of these commercial companies that in the end must answer to shareholders and annual reporting periods.

To deal with existing concentrations (legacy issues) of risk that might struggle to obtain affordable insurance from the private sector, we examine relatively new financial instruments called Catastrophe (CAT) bonds that transfer insurance risks to the capital markets. In particular we consider a hypothetical Sydney flood CAT bond for residential buildings and contents in the Hawkesbury River basin. The methodology is easily transferrable to other location-specific perils such as bushfires. The cost of transferring flood risk in the Hawkesbury River basin using a Catastrophe (CAT) bond was estimated to be around 15 to 75% higher than that of traditional reinsurance. Whether this difference is too much to pay for *guaranteed* security is a business decision for individual insurers and/or governments.

The real issue here is that climate change is a complex policy area and no easy answers emerged from our deliberations, at least in respect to the employment of insurance instruments. It should be clearly kept in mind that insurance is a mechanism that transfers disaster risk; it does not do away with the risk. On the other hand, measures such as risk-informed land-use development, improved building codes and flood defences can dramatically reduce the risk in exposed areas and thus the need to transfer this risk. Any gains achieved here will put us in good stead for additional changes that a warming climate may eventually throw at us.

1. EXECUTIVE SUMMARY

Insurance is a mechanism that makes the cost of managing risk more affordable through sharing the risks and the reduction in uncertainty resulting from this. This report comprises effectively three different insurance-related studies undertaken under the umbrella of NCCARF project S11-17 entitled: *Assessing the potential for and limits to insurance and market based mechanisms for encouraging climate change adaptation.*

Each study is presented in a different self-contained section. Section 3 provides an updated review of the peer-reviewed scientific literature looking at the causes of the rising insured and economic costs of natural disasters. Section 4 summarises various attempts by governments to get involved in the provision of natural catastrophe insurance and the degree to which this involvement encourages disaster risk reduction and climate change adaptation. The discussion has high currency in Australia, given the call from some quarters after the 2011 Queensland floods that the Australian government become involved in the insurance market. Section 5 deals with relatively new insurance structures called Catastrophe (CAT) Bonds, which transfer risk to the capital markets and which may present one option for insuring the legacy risk problem caused by the uninhibited development in at-risk locations and which could be amplified under a warming climate. Lastly, Section 6 discusses gaps and future research directions.

The peer-reviewed scientific literature shows that the rising costs of natural disasters from extreme weather is mainly explained by growing concentrations of population and wealth in disaster-prone regions, although a climate change contribution cannot be ruled out. At least in the case of US tropical cyclone, recent studies suggest that we may be several decades to centuries away from being able to detect with high statistical confidence an anthropogenic climate change signal in the losses. Given such long and uncertain time frames, policy-making in relation to climate change adaptation will of necessity take place in an environment of uncertainty and ignorance; this reality strengthens the case for encouraging adaptation to the current climate.

It is argued those hazard-resilient construction standards, risk-informed land use planning and flood defences are all key to reducing the cost of natural disasters. Building codes are normally considered at the level of an individual home and focussed on life-safety. However management of the overall economic impact means that building code design should also reflect the future impact of large disasters on the overall economy.

In Section 4 we examine the potential for the insurance sector to be a positive actor in helping reduce this nation's exposure to the risk of extreme weather. Since this is not a responsibility that the insurance sector can shoulder on its own, we also consider the regulatory environment, in other words, the role of government, who, by acting in concert with the free market, may be able to encourage community resilience to extreme weather events and manage any additional impacts caused by global climate change.

With this in mind, we have reviewed the provision of catastrophe insurance in a number of different countries and the involvement of government in various *residual market schemes*. Each scheme reflects particular history, hazard profile and culture. Government pools have certain advantages over the private sector in being able to spread losses across time onto future generations and being generally exempt of federal taxes on surpluses.

An ongoing contentious issue, especially in the US, has been the degree of political influence exerted on the pricing of residual market mechanisms. In an attempt to keep prices affordable and encourage take-up rates, there has been a tendency to keep premiums low and to have policyholders in low- and high-risk areas being charged similar rates. This means that policyholders in risk-prone areas are being subsidised by homeowners in low risk areas and development in high-risk areas encouraged. The increasing catastrophe liability is making these schemes unsustainable.

Outside of the US, the situation varies from country to country but in none of the arrangements examined have premiums been truly risk-adjusted, although the technology to do this is increasingly available. This means that the price signal of risk to homeowners and governments is diluted with little incentive for either to engage in risk reducing behaviours. None of the schemes examined provide a clear model for Australia and this country should reflect very carefully before introducing any government pool to deal with natural catastrophe risks.

The key mechanism by which insurance products can encourage behavioural change is by charging premiums based on the extant risk. And to the extent that this reduces exposure to natural disasters, it will bring about a contemporaneous reduction in community vulnerability to any future climate change enhancement of extreme weather.

Given the legacy of uninhibited development in many hazard-prone areas to date, in Australia as elsewhere, it is likely there will always be concentrations of risk where insurance, even when offered, becomes unaffordable. To deal with this circumstance we examine the utility and pricing of Catastrophe (CAT) Bonds, new financial instruments that transfer risk to the capital markets. By way of example we price such a hypothetical bond to deal with flood risk in the Hawkesbury-Nepean catchment in NSW. The cost of such a bond is shown to be greater than traditional reinsurance but it may still be an option for governments seeking to finance the post-event recovery of some communities. While CAT Bonds or traditional insurance are an alternative to ad-hoc post-event government largess, they are not an alternative to prudent and risk informed land-use development.

Lastly we note that at its core insurance is about the financial management of *uncertainty* and the tools it employs to assess this uncertainty may be more generally useful in reframing the debate over climate change. Acknowledging the uncertainty in the impacts of climate change on extreme weather as indicated above may help move us beyond the sterile debate between the mutually exclusive 'certainty' of the sceptics, on the one hand, and that of the proponents for dramatic societal action on the other. To the degree that uncertainty has a positive price - the more uncertain the outcome, the higher the premium required to replace this outcome with a certain one - then investment in climate change adaption and disaster risk reduction can both be seen as complementary and prudent hedges against the worst outcomes.

2.   OBJECTIVES OF THE RESEARCH

The main objectives in this project were:

1. Review the capacity of the insurance sector to deal with increasing cost of catastrophe risks in a warming world,

2. Review the successes and failures of government involvement in insurance markets and identify policy options for encouraging climate change adaptation outcomes in an effective, efficient and equitable manner,

3. Explore the capability of capital market instruments and insurance-linked securities to deal with legacy issues posed by concentrations of development in areas of very high-risk to riverine flood, bushfire and storm surge, and

4. Propose a government regulatory framework that will encourage the insurance industry to play a positive role in increasing the resilience of communities in recovering from catastrophe weather risks in a warming climate.

3. THE RISING COST OF DISASTER LOSSES AND ITS IMPACT ON THE INSURANCE SECTOR

3.1 Abstract

Economic and insured costs of natural disasters are rising in the main because of increasing concentrations of population and wealth in hazard prone areas. At least to this juncture, analyses of long-term trends in the loss histories from extreme weather likely to cause property damage -- tropical cyclones, floods, bushfires and storms -- cannot be attributed to anthropogenic climate change, although a climate change contribution is not ruled out (IPCC 2012). The 2011 Thailand floods showed that disaster losses in Asia will increasingly contribute to the global economic cost of natural disasters as populations and wealth rise in this region.

Recent studies suggest that we may be several decades to centuries away from being able to detect a *statistically significant* anthropogenic climate change signal in economic losses arising from land falling hurricanes in the US. Such event losses are a major driver of global insurance losses. Given these timescales and the degree to which global losses are correlated with US hurricane losses, policy making in respect to the management of the possible amplification of losses due to climate change must necessarily occur under uncertainty and ignorance. This situation strengthens the case for expanding disaster risk reduction as part of any climate change adaptation policy.

Insurance plays a critical role in providing funds for economic recovery after a catastrophe, but purchasing insurance merely transfers risk, it does not reduce or eliminate the risk. The insurance system can provide incentives for loss mitigation by sending price signals reflecting actual risk. Post-disaster government largess and, in some parts of the world, government-subsidised insurance premiums effectively encourage development in hazard-prone areas. Overcoming this problem is not an impossible task: most areas of high risk in Australia are already well known, but decreasing vulnerability to natural hazards will require hard and potentially unpopular political decisions. The benefits that have been accorded the Australian public and the economy through wind-resilient construction in tropical cyclone-prone parts of the country show what can be achieved given political will and a demonstrated need.

Risk reduction measures can be viewed from different perspectives: life safety, protection of individual properties, and management of overall economic impact. While building codes have traditionally focused on the first two, the authors argue that consideration also needs to be given to the future potential for large disaster losses in the areas where building codes apply. More deliberation of large loss scenarios is needed to guide policy and raise awareness of these issues.

3.2 Introduction

This Chapter examines the rising cost of losses (economic and insured) arising from natural disasters and the implications that this circumstance may have for the global insurance market. The insurance market includes both direct insurers, and global reinsurers, who ultimately accept much of the risk. The increase in disaster losses has led to concern that anthropogenic climate change is contributing to this trend. In response to this concern, numerous studies have examined the factors responsible for this increase. This report summarises these efforts as well as recent efforts to estimate the timescale at which an anthropogenic climate change signal might be detectable in the US tropical cyclone losses.

We pay particular attention to tropical cyclones because the risk concentration posed by US exposure to this peril has implications for the cost of risk transfer and thus for insurance premiums worldwide. Tropical cyclones (TC) account for six of the 10 most costly inflation-adjusted insured natural disaster losses (2011 dollars) between 1970 and 2011 (Swiss Re, 2012a). Of these six, all impacted the US and surrounding areas. Moreover we take advantage of a wealth of peer-reviewed and contemporary studies of normalised US TC losses that go back more than a century (e.g. Pielke and Landsea (1998) and Pielke et al. (2008)) and downscaling studies of projected basin-wide hurricane activity under a warming climate (Bender et al. 2010). While other hazards may play out differently, if we can't find a climate change signal in US hurricane losses then we are going to struggle to find it in other loss databases.

The rising risk exposure to tropical cyclone (and other weather-related perils) in Asia due to rapidly increasing concentrations of population and wealth in this region poses further challenges to the global insurance sector. An important component of catastrophe risk management is the development of adequate and sustainable financial protection for victims of future disasters and our report discusses this financial management.

Our focus here will be property damage. This follows since property damage is an increasingly the major determinant of economic losses due to natural disasters as the death rate from natural disasters decreases. To illustrate this point, Figure 1a and b shows the declining Australian death rate from natural disasters as recorded in Risk Frontiers' PerilAUS database (Coates, 1996; Haynes et al. 2010; Crompton et al., 2010a). Globally the pattern is similar with the average annual deaths from natural disasters appearing to have stabilised at around 50,000 since the 1970's (Swiss Re, 2012a); for comparison, deaths from motor vehicles are currently estimated to be of the order of 1.3 million per year (WHO, 2012). This means that in respect of disasters, economic losses are assuming a much greater relative importance than in the past when the major focus of disaster risk reduction was on reducing loss of life (Walker, 2011).

This paper adopts a risk-based perspective where risk is considered a function of: the *hazard* as expressed by the intensity and frequency of the peril, the *exposure* -- the spatial distribution of assets and their value --, and the *vulnerability* of assets to the intensity of the peril. (There are also behavioural dimensions to risk (Slovic, 1999); but these lie outside the scope of the present study.) It is understandable that discussion over the likely impacts of anthropogenic climate change in Australia has been preoccupied with disputes about the veracity of modelled climate projections, but changes in exposure and vulnerability also influence future risk and cannot be ignored. Moreover reducing vulnerability has intrinsic value irrespective of how anthropogenic climate change influences the future frequency and intensity of extreme weather events.

In what follows, we argue that it is especially important to expand disaster risk reduction in climate adaptation policy given that an anthropogenic climate change signal may not be statistically significant in disaster loss records for at least several decades.
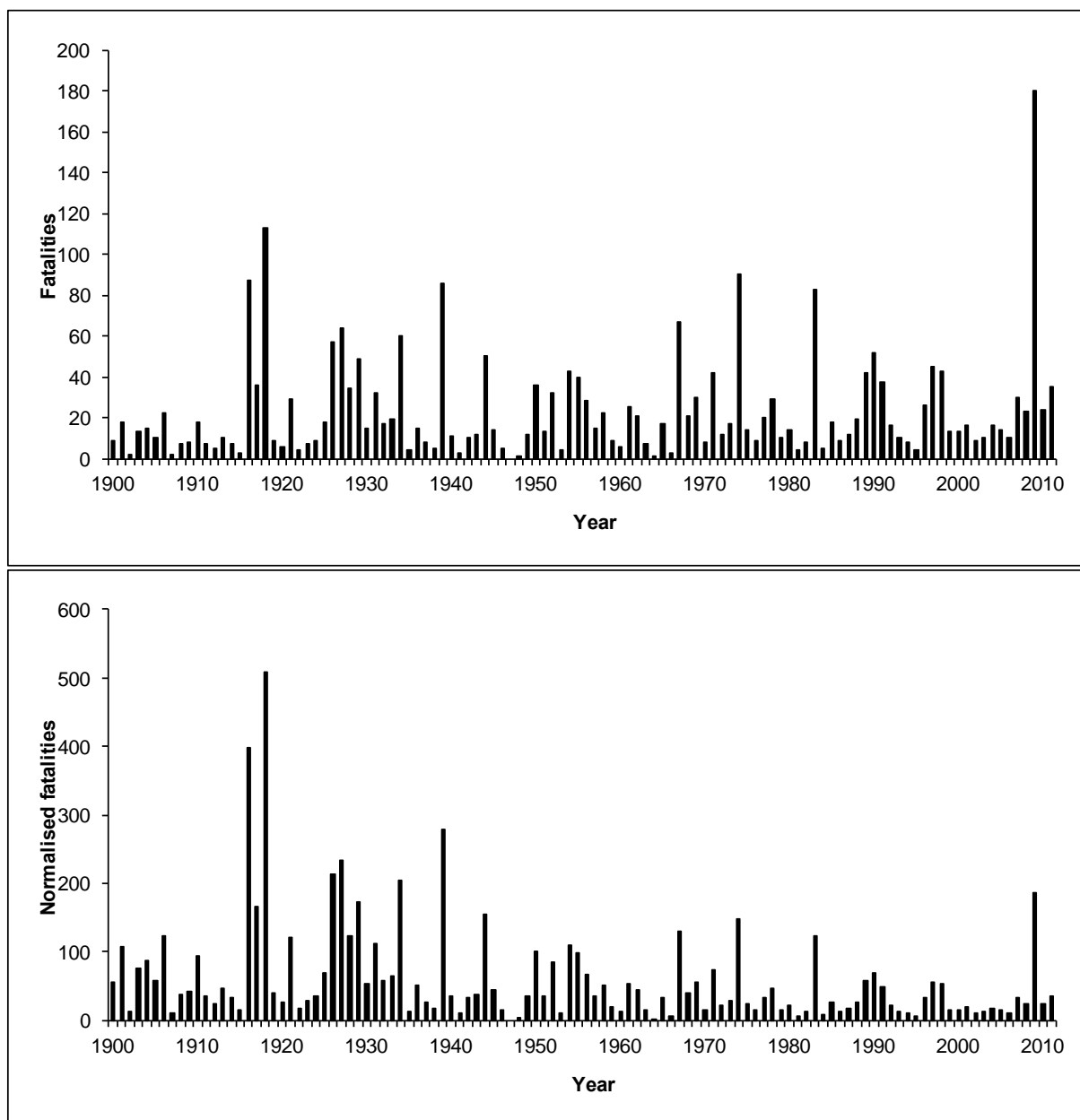
Figure 1: (a) number of fatalities arising from natural perils in Australia since 1900; (b) as for (a) but with numbers of fatalities normalised by population (Source: PerilAus, Risk Frontiers).

3.3 Loss normalisation

Before comparisons between the impacts of past and more recent natural hazard events can be made, various societal factors known to influence the magnitude of losses over time must be accounted for. This adjustment process has become known as *loss normalisation* (Pielke and Landsea, 1998).

Normalising losses to a common base year is undertaken primarily for two reasons: first, to estimate the losses sustained if historic events were to recur under current societal conditions, and secondly, to examine long term trends in disaster loss records with a view to exploring what portion of any trend remaining after taking societal factors

into account may be attributed to other factors including climate change – due to natural variability or anthropogenic causes.

Climate-related influences stem from changes in the frequency and/or intensity of natural perils -- tropical cyclones, storms including hail storms, floods, bushfires -- whereas socio-economic factors comprise changes in the vulnerability and exposure to the natural hazard. Socio-economic adjustments have largely been limited to accounting for changes in exposure, although Crompton and McAneney (2008) adjusted Australian tropical cyclone losses for the influence of improved building standards introduced around the early 1980s following the destruction of Darwin by Tropical Cyclone Tracy (Mason et al., 2012).

Bouwer (2011) provides a comprehensive review of loss normalisation studies (Table 1). The key conclusions from the 21 weather-related disaster loss studies are that economic losses have increased around the globe but no trends in losses adjusted for changes in population and wealth could be attributed to anthropogenic climate change. Studies published since the Bouwer (2011) review confirm his key findings. Two of these studies - Neumayer and Barthel (2011) and Barthel and Neumayer (2012) – were funded by the global reinsurer Munich Re and utilise their NatCatSERVICE natural disaster loss database. Neumayer and Barthel (2011) found substantial increases in losses in their global analysis of the economic losses from natural disasters during 1980-2009. However, they found no significant upward trend once losses were normalised, and this was the case globally, for specific disasters or for specific disasters in specific regions.

Barthel and Neumayer (2012) undertook trend analyses of normalised insured losses due to different natural perils including tropical cyclones at the global scale over the period 1990 to 2008, for West Germany for the period 1980 to 2008 and for the US from 1973 to 2008. Within these limited time frames, they found no significant trends at the global level, but claimed statistical significance for upward trends for all non-geophysical hazards as well, as for certain specific disaster types in the US and West Germany. The authors expressly warn against taking their findings for the US and Germany as conclusive evidence that climate change was already causing more frequent and/or more intensive natural disasters affecting these countries. They refer to the now well-documented issues confounding statistical analyses of loss data over short time series (e.g. the Hohenkammer consensus (Hoppe and Pielke Jr, 2006; Bouwer et al. 2007): the findings reported could merely reflect natural climate variability and have nothing to do with anthropogenic climate change. Importantly and echoing many other studies, they conclude:

> *Climate change neither is nor should be the main concern for the insurance industry. Accumulation of wealth in disaster prone areas is and will always remain by far the most important driver of future economic disaster damage.*

Other recent analyses that report no trend in normalised losses that might be attributable to anthropogenic climate change include those of: Zhang et al. (2011) – tropical cyclone economic losses in China over the period 1984-2008; Barredo et al. (2012) – insured losses from floods in Spain between 1971 and 2008, and Simmons et al. (2012) – US tornado economic damage from 1950-2011.

Table 1: Normalisation studies of disaster loss records. From Bouwer, L. M., 2011: Have disaster losses increased due to anthropogenic climate change? *Bull. Amer. Meteorol. Soc.*, 92, 39-46. © American Meteorological Society. Used with permission.

Hazard	Location	Period	Normalisation	Normalised loss	Reference
Bushfire	Australia	1925-2009	Dwellings	No trend	Crompton et al. (2010a)
Earthquake	United States	1900-2005	Wealth, population	No trend	Vranes & Pielke (2009)
Flood	United States	1926-2000	Wealth, population	No trend	Downton et al. (2005)
Flood	China	1950-2001	GDP	Increase since 1987	Fengqing et al. (2005)
Flood	Europe	1970-2006	Wealth, population	No trend	Barredo (2009)
Flood	Korea	1971-2005	Population	Increase since 1971	Chang et al. (2009)
Flood & landslide	Switzerland	1972-2007	None	No trend	Hilker et al. (2009)
Hail	United States	1951-2006	Property, insurance market values	Increase since 1992	Changnon (2009a)
Windstorm	United States	1952-2006	Property, insurance market values	Increase since 1952	Changnon (2009b)
Windstorm	Europe	1970-2008	Wealth, population	No trend	Barredo (2010)
Thunderstorm	United States	1949-98	Insurance coverage, population	Increase since 1974	Changnon (2001)
Tornado	United States	1890-1999	Wealth	No trend	Brooks & Doswell (2001)
Tornado	United States	1900-2000	None	No trend	Boruff et al. (2003)
Tropical storm	Latin America	1944-99	Wealth, population	No trend	Pielke et al. (2003)
Tropical storm	India	1977-98	Income, population	No trend	Raghavan & Rajesh (2003)
Tropical storm	United States	1900-2005	Wealth, population	No trend	Pielke et al. (2008)

Tropical storm	United States	1950-2005	Asset values	Increase since 1970; no trend since 1950	Schmidt et al. (2009a)
Tropical storm	China	1983-2006	GDP	No trend	Zhang et al. (2009)
Tropical storm	United States	1900-2008	GDP	Increase since 1900	Nordhaus (2010)
Weather (flood, thunderstorms, hail, bushfires)	Australia	1967-2006	Dwellings, dwelling values	No trend	Crompton & McAneney (2008)
Weather (hurricanes, floods)	United States	1951-97	Wealth, population	No trend	Choi & Fisher (2003)
Weather (hail, storm, flood, wildfire)	World	1950-2005	GDP, population	Increase since 1970; no trend since 1950	Miller et al. (2008)

[1]Gross domestic product (GDP) is a measure of a country's overall official economic output. It is the market value of all final goods and services produced in a country in a given year.

The recently released Special Report of the Intergovernmental Panel on Climate Change (IPCC) 'Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation' (SREX) (IPCC, 2012) offers the most up-to-date assessment on the science of extreme events and disasters and supports the findings previously discussed:

> *Increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from weather- and climate-related disasters (high confidence). Long-term trends in economic disaster losses adjusted for wealth and population increases have not been attributed to climate change, but a role for climate change has not been excluded (high agreement, medium evidence).*

Studies such as those by Weinkle et al. (2012) add further confidence to the findings of tropical cyclone loss normalisation studies. They created a homogenised dataset of global tropical cyclone landfalls and found no long-period global or individual basin trends in the frequency or intensity of landfalling tropical cyclones of minor or major hurricane strength. This supports the conclusion that increasing tropical cyclone losses around the globe are largely explained by increasing populations and wealth.

Land use planning and hazard resilient construction standards are important influences on natural disaster losses and are frequently discussed in loss studies. Crompton and McAneney (2008) normalised Australian weather-related insured losses over the period 1967-2006 to 2006 values. Insured loss data were obtained from the Insurance Council of Australia (ICA) (http://www.insurancecouncil.com.au/). The methodology adjusted for changes in dwelling numbers and nominal dwelling values (excluding land value). In a marked point of departure from previous normalisation studies, the authors applied an additional adjustment for tropical cyclone losses to account for improvements in construction standards mandated for new construction in tropical cyclone-prone parts of the country (Mason et al., 2012). They emphasise the success of improved building standards in reducing building vulnerability and thus tropical cyclone wind-induced losses.

Figures 2a and b show the annual aggregate losses and the annual aggregate normalised losses (2011/12 values) for weather-related events in the ICA Disaster List. These figures are updated from Crompton and McAneney (2008) using a refined methodology described in Crompton (2011).
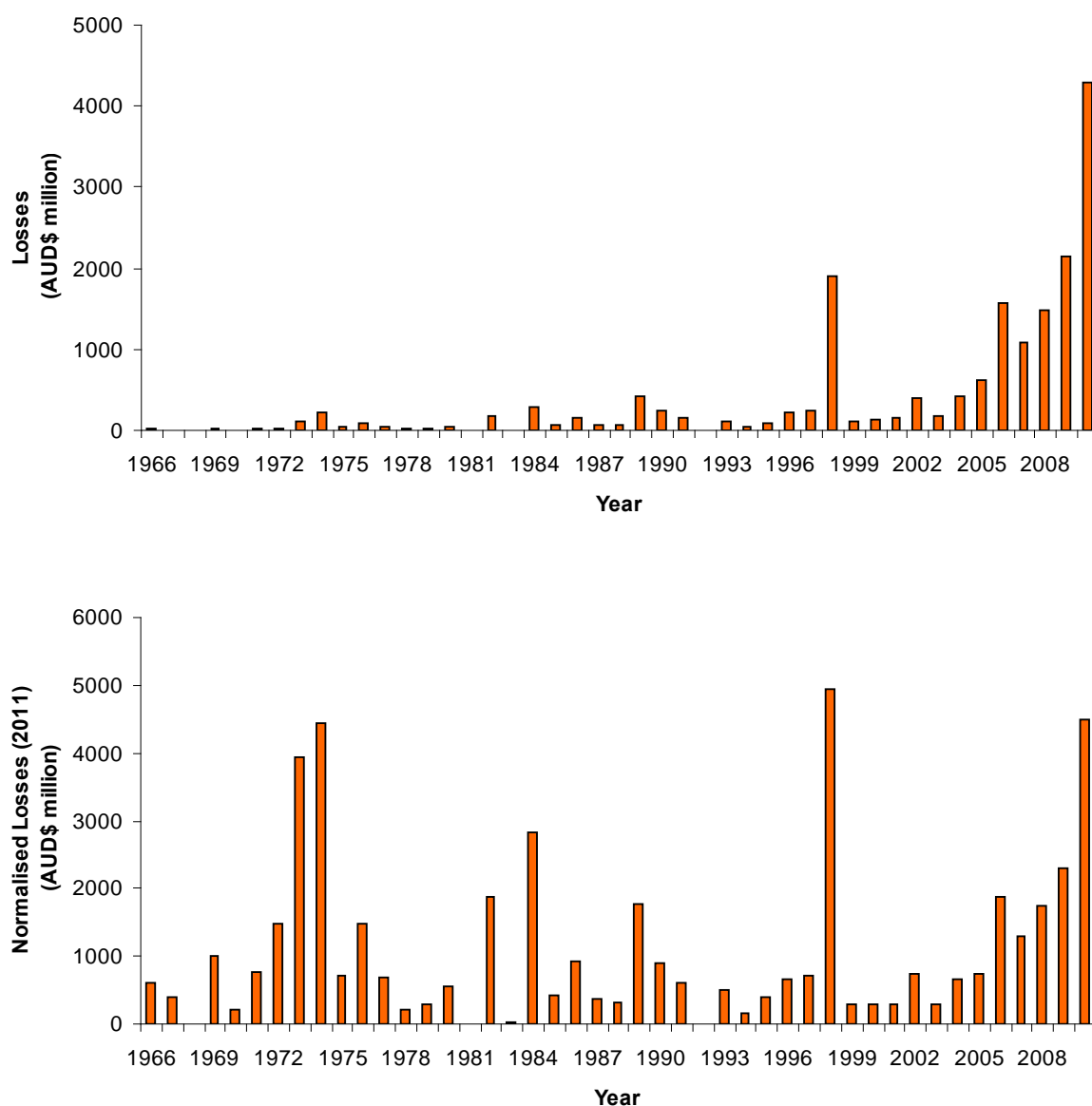
Figure 2: (a) annual aggregate insured losses (AUD$ million) for weather-related events in the ICA Disaster List for years beginning 1 July; (b) as in (a) but with losses normalised to 2011/12 values (source : Crompton (2011)).

Following the large loss of life and building damage in the 2009 bushfire (wildfires) in Victoria, Australia, Crompton et al. (2010a) examined the history of fatalities and property damage since 1925. Once the loss data was adjusted for increases in population and dwelling numbers respectively, no residual trends were found that could be attributed to climate change due to the emission of greenhouse gases. The authors emphasise the large proportion of buildings destroyed in the 2009 fires that either lay within bushland or at very small distances from it (<10 m) and the role that poor land use planning policies in bushfire-prone parts of Australia have played in increasing the risk that bushfires pose to the public and the built environment. These same conclusions were made by Chen and McAneney (2010) in an invited submission to the 2009 Victorian Bushfire Royal Commission.

Although not normalisation studies, those by Di Baldassarre et al. (2010) and Van der Vink et al. (1998) also point to societal factors being the driving forces behind rising disaster losses. Based on the results of both continental and at-site analyses, Di Baldassarre et al. (2010) found that the magnitude of African floods has not significantly increased during the 20th Century, and that climate has not been a consequential factor in the observed increase in flood damage.
They conclude that:

> *. . . the intensive and unplanned urbanization in Africa and the related increase of people living in floodplains has led to an increase in the potential adverse consequences of floods and, in particular, of the most serious and irreversible type of consequence, namely the loss of human lives . . . most of the recent deadly floods have happened where the population has increased more.*

Van der Vink et al. (1998) also concluded that the US was becoming more vulnerable to natural disasters because more property was being placed in harm's way. They state that:

> *In many ways the trends [in losses] seem paradoxical. After all, most natural disasters occur in areas of known high risk such as barrier islands, flood plains, and fault lines. Over time, one would expect that the costs of natural disasters would create economic pressures to encourage responsible land use in such areas.*

> *. . . the economic incentives for responsible land use have been stifled by legislated insurance rates and federal aid programs that effectively subsidize development in hazardous areas. And while there will always be great political pressure to provide economic relief after a disaster, there has been little political interest in requiring pre-disaster mitigation.*

Many of the above statements hold true for Australia. The issue of subsidised development and the political interference with insurance premiums in some US states will be dealt with in Section 4 of this report.

3.4 Future loss sensitivity

A number of studies have projected disaster losses. This has been done to either quantify the effect of anthropogenic climate change (for example due to a projected change in tropical cyclone frequency and/or intensity) on its own, or to compare the effect of projected changes in both exposure and climate. Future losses will also be sensitive to changes in vulnerability, but this factor is often held constant.

Table 2 (from Bouwer (2013) summarises the results of such studies on the estimated change in disaster losses in 2040 under projected climate and exposure changes, relative to 2000. Table 3 (from Crompton et al. (2010b)) provides a more detailed account of some of the more recent US tropical cyclone studies. The logic usually employed in these studies is to examine the effects over a given time horizon: it entails calculating (a) the projected change in the hazard compared with the present day – an anthropogenic climate change multiplier, (b) the projected change in the exposure and (c) the combination of these two factors.

Anthropogenic climate change
The anthropogenic climate change influence on disaster losses arising from a given emission scenario and changes in the hazard projection. This is then combined with a relationship between the hazard normalised damages and intensity (for example wind speed in the case of tropical cyclones) (referred to as 'loss function' (Table 3)) in order to estimate the projected increase in losses due to these changes.

Exposure
Projected proportional change in population and wealth

Total Multiplier
Anthropogenic climate change Multiplier + Exposure Multiplier + Anthropogenic climate change Multiplier × Exposure Multiplier + 1

Tables 2 and 3 are based on a limited number of studies: missing are changes in the likely frequency of bushfires, droughts and heatwaves. There is also a large spread in estimates, and the studies employ different approaches and assumptions. For example, Pielke (2007) adopted a conservative approach in deliberately selecting upper end estimates for the anthropogenic climate change effect on tropical cyclone intensity. While the focus of Table 2 is on average changes, the economic consequences of more frequent high impact events may be severe and attention should also be paid to the full loss distribution.

Despite the various assumptions made in each of the studies in Table 3, the estimated changes in future tropical cyclone losses in the US resulting from anthropogenic climate change fall into two broadly similar pairs of studies. The Pielke (2007) lower estimate extrapolated to 2100 is approximately +128%, a figure comparable to the Nordhaus (2010) central estimate of +113%. On the other hand, linearly extrapolating the Schmidt et al. (2009b) estimate to 2090 results in an approximate +20% change in loss, whereas the Bender et al. (2010) ensemble-mean estimate is +28%.

Both Pielke (2007) and Schmidt et al. (2009b) show that exposure growth will have a greater effect than anthropogenic climate change on future US losses. Pielke (2007) adopted a conservative approach in deliberately selecting upper end estimates for the anthropogenic climate change effect on tropical cyclone intensity. Schmidt et al. (2009b) note that the loss results in an additional loss of wealth in the sense that it increases loss over and above the proportional increase in exposure (capital stock).

The following statement from SREX report (IPCC, 2012) reflects the conclusions of the studies discussed above:

> *In many regions, the main drivers of future increases in economic losses due to some climate extremes will be socioeconomic in nature (medium confidence, based on medium agreement, limited evidence) (IPCC, 2012).*

Mendelsohn et al. (2012) also consider future hurricane damage. They examine a range of scenarios for how tropical cyclone damage will increase to 2100. The study used the same four models as did Emanuel (2011) (see later discussion). In absolute terms, climate change is found to increase global tropical cyclone damage in 2100 in each of the four models used. On average, socio-economic trends and climate change are each responsible for a doubling of damage, resulting in a fourfold increase, from US$26 billion per year at present to US$109 billion in 2100.

Mendelsohn et al. (2012) explain that their findings are consistent with most of the existing work concerning the effect of climate change on damage induced by tropical cyclones.

3.5 Timescale at which an anthropogenic climate change signal might be observed in US tropical cyclone loss data

A study by Crompton et al. (2011) follows on from those detailed above. Their starting point is that research to date has been unable to detect an anthropogenic climate change influence on Atlantic tropical cyclone behaviour and concomitant damage, though such an influence is projected in the future (Knutson et al., 2010). This being the case, Crompton et al. (2011) posed the question: if changes in storm characteristics occur as projected, then on what timescale (*the so-called emergence timescale*) might we expect to detect the effects of these changes in the damage data?

Crompton et al. (2011) use the Bender et al. (2010) Atlantic storm projections published in the journal *Science* and the Pielke et al. (2008) normalised loss data to show that statistically significant anthropogenic signals are very unlikely to emerge in a time series of normalised US tropical cyclone economic losses at timescales of less than a century. Results were dependent on the global climate model(s) underpinning down-scaling projections with emergence timescales ranging between 120 and 550 years. It took 260 years for an 18-model ensemble-based signal to emerge, at which time losses are expected to increase by 106%. This result is mathematical: no further assumptions are introduced beyond those employed by Bender et al. (2010).

The main message is that, from the projections analysed, it will be quite some time before it can be said with any level of scientific certainty that anthropogenic climate change is influencing US tropical cyclone losses. The authors extended this caution more generally to global weather-related natural disaster losses to the extent that these are correlated with US tropical cyclone losses. They point out that short term variability is not 'climate change', which the IPCC defines on timescales of 30-50 years or longer, and that their results argue very strongly against using abnormally large losses from individual Atlantic hurricanes or seasons as evidence of anthropogenic climate change.

Crompton et al. (2011) also confirm the general agreement that it is far more efficient to seek to detect anthropogenic signals in hurricane activity data directly rather than in hurricane loss data. This is because there is large variance in the normalised loss history - two events of the same intensity can hit different areas of the US and generate very different losses depending on a number of local factors such as the strength of buildings and the economic wealth. Moreover, annual loss data can comprise losses from different Saffir-Simpson category events and the projected changes in frequency of events in these categories have different magnitudes and directions.

Table 2: Estimated change in extreme weather losses in 2040 due to climate change and exposure change, relative to the year 2000 from 22 impact studies. From Bouwer, L. M., 2013; Projections of future extreme weather losses under changes in climate and exposure. *Risk Analysis*, 33, 915-930. © 2012 Society for Risk Analysis. Reprinted with permission from John Wiley and Sons.

No.	Hazard type	Region	Estimated loss change [%] in 2040				Reference
Climate change							
			Min	Max	Mean	Median	
1	Tropical cyclone	Global	58	1365	417	30	Pielke (2007)
2	Tropical cyclone	USA	12	92	47		Nordhaus (2010)
3	Tropical cyclone	Global, low lat.	23	130	46		Narita et al. (2009)
4	Tropical cyclone	USA	-	-	22		Hallegatte (2007)
5	Tropical cyclone	USA, Caribbean	19	46	32		ABI (2005a; 2005b)
6	Tropical cyclone	Japan	20	45	30		ABI (2005a; 2005b)
7	Tropical cyclone	China	9	19	14		ABI (2009)
8	Tropical cyclone	USA	-	-	9		Schmidt et al. (2009b)
9	Tropical cyclone	USA	-27	36	14		Bender et al. (2010)
10	Extra-tropical cyclone	Global, high lat.	-11	62	22	15	Narita et al. (2010)
11	Extra-tropical cyclone	Europe	6	25	16		Schwierz et al. (2010)
12	Extra-tropical cyclone	UK, Germany	-6	32	11		Leckebusch et al. (2007)
13	Extra-tropical cyclone	Europe	-	-	14		ABI (2005a; 2005b)
14	Extra-tropical cyclone	UK	-33	67	15		ABI (2009)
15	Extra-tropical cyclone	Netherlands	80	160	120		Dorland et al. (1999)
16	River flooding	Netherlands	46	201	124	83	Bouwer et al. (2010)
17	River flooding	Europe	-	-	83		Feyen et al. (2009)
18	River flooding	UK	3	11	7		ABI (2009)
19	River flooding	Rhine Basin	57	213	135		Te Linde et al. (2011)
20	River flooding	Spain (Madrid)	-	-	36		Feyen et al. (2009)
21	River flooding	Australia	67	514	361		Schreider et al. (2000)
22	Local flooding	Netherlands	16	70	47		Hoes et al. (2005), Hoes & Schuurmans (2006), Hoes (2007)

Exposure change						
No.	Hazard type	Region	Estimated loss change [%] in 2040			Reference
			Min	Max	Mean	
1	Tropical cyclone	Global	164	545	355	Pielke (2007)
8	Tropical cyclone	USA	-	-	240	Schmidt et al. (2009b)
15	Extra-tropical cyclone	Netherlands	12	93	50	Dorland et al. (1999)
16	River flooding	Netherlands	35	172	104	Bouwer et al. (2010)
19	River flooding	Rhine Basin	10	36	23	Te Linde et al. (2011)
20	River flooding	Spain (Madrid)	-	-	349	Feyen et al. (2009)
22	Local flooding	Netherlands	-4	72	29	Hoes et al. (2005), Hoes & Schuurmans (2006), Hoes (2007)

Table 3: Overview of recent US future loss sensitivity studies (source: Crompton et al. (2010b)).

		Anthropogenic climate change effect				Exposure effect		Total effect
Study	Year	Emission scenario	Tropical cyclone projections	Elasticity of damages w.r.t. wind speed[1]	Change in loss	Variable(s)	Change in loss	Change in loss
Pielke (2007)	2050		Intensity: +18% (upper end of estimates[2]) Frequency: no change	3, 6, 9 (Derived value: 3.9)	Range: +64% to +344%	Population & wealth	+180%, +600% Baseline year: 2000	Range: +460% to +3105%
Schmidt et al. (2009b)	2050	IPCC A1	Intensity: +3%[3] Frequency: no change	3 (Derived value: 2.8)	+11%	Capital stock	+297% Baseline year: 2005	+317%
Bender et al. (2010)	2090	IPCC A1B	Changes in damage potential were estimated by combining the percent of historical damage[4] by Saffir-Simpson category with their 80-year model-based projected percent change in hurricane frequency by category.		18-model ensemble mean: +28% Range: -54% to +71%	-	-	-
Nordhaus (2010)93	2100	Doubling of CO_2	Intensity: +8.7%[5], +13.7%[6] Frequency: no change	3, 7.27, 9 (Derived value: ≈ 9)	Central estimate: +113% Range: +29% to +219%	-	-	-

[1] This refers to the exponent or power of wind speed that damage is assumed proportional to, e.g. damage α (wind speed)^y.
[2] Estimates were based on expert elicitation.
[3] Based on Bengtsson et al. (2007).
[4] Pielke et al. (2008) normalized losses.
[5] Calculated using the Knutson and Tuleya (2004) intensity / SST relationship assuming a 2.5^{o}C increase in sea surface temperature (SST).
[6] Based on Emanuel (2005) assuming a 2.5^{o}C increase in SST.

Elasticity: Pielke (2007), Schmidt et al. (2009b) and Nordhaus (2010) all derived loss functions using per-storm normalized US hurricane losses and maximum wind speed at landfall reported by the National Hurricane Centre. Pielke (2007), Schmidt et al. (2009b) and Nordhaus (2010) used normalized losses from 1900 to 2005, 1950 to 2005 and 1900 to 2008 respectively.

Emanuel (2011) implemented an alternative methodology to Crompton et al. (2011) to assess under various scenarios when the signal of human-caused climate change would be detectable in the damage record of Atlantic hurricanes. He considered four models, three of which showed increasing losses and one a small decrease. Of the three models that showed increasing losses, the time until detection was estimated to be 40, 113 and 170 years. Regardless of differences with the results of Crompton et al. (2011), both studies are in agreement that the time to detection of a signal of human-caused climate change, assuming that recent projections are correct, is a very long time.

3.6   The disaster mitigation challenge

Recent catastrophes have highlighted many challenges, including how to best organise systems to pay for the damage caused by natural disasters and how to mitigate their effects. Insurance (public and private) plays a critical role in providing funds for economic recovery after a catastrophe. Insurance, however, merely transfers risks to others with a broader diversification capacity; simply purchasing insurance does not reduce the risk. In principle the insurance system can play a critical role in providing incentives for loss mitigation by sending price signals reflecting risk (Roche et al., 2010) but regulatory efforts to limit premium increases in high risk areas, as has occurred in some parts of the US, can diminish the insurance system's ability to perform this function. This issue is pursued in Section 4 of this report.

Disaster mitigation measures can offset some of the upward pressure demographic and economic drivers are exerting on natural disaster losses. In a study for the Australian Building Codes Board, McAneney et al. (2007) estimated that the introduction of building code regulations requiring houses to be structurally designed to resist wind loads had reduced the average annual property losses from tropical cyclones in Australia by some two-thirds. Their estimate was based on the likely losses had the building code regulations never been implemented or had they always been in place.

Kunreuther and Michel-Kerjan (2009) also examined this same question by analysing the impact that disaster mitigation would have had on reducing losses from hurricanes in four states in 2005: Florida, New York, South Carolina, and Texas. They considered two extreme cases: one in which no one invested in mitigation and the other in which everyone invested in predefined mitigation measures. A hurricane catastrophe loss model developed by Risk Management Solutions (RMS) was used to calculate losses for each scenario. The analyses revealed that mitigation has the potential to significantly reduce losses from future hurricanes with reductions ranging from 61% in Florida for a 100-year return period loss to 31% in Texas for a 500-year return period loss. In Florida alone, mitigation was estimated to reduce losses by $51 billion for a 100-year event and $83 billion for a 500-year event.

Despite the reductions in risk that could be achieved, many homeowners, private businesses, and public-sector organisations fail to voluntarily adopt cost-effective loss-reduction measures, particularly if regulatory actions inhibit the insurance system from providing sufficient economic incentives to do so. In addition, the magnitude of the destruction following a catastrophe often leads governmental agencies to provide disaster relief to victims – even if prior to the event the government claimed that it would not do so. This phenomenon has been termed the 'natural disaster syndrome' (Kunreuther, 1996). This combination of underinvestment in protection prior to a

catastrophic event and taxpayer financing of part of the recovery following can be critiqued on both efficiency and equity grounds.

Absent regulations, the challenge lies in encouraging residents in hazard-prone areas to invest in mitigation measures. Even after the 2004 and 2005 US hurricane seasons, a large number of residents in high-risk areas still had not invested in relatively inexpensive loss-reduction measures, nor had they undertaken emergency preparedness measures. A survey of 1,100 residents living along the Atlantic and Gulf Coasts undertaken in May 2006 revealed that 83% had taken no steps to fortify their home, 68% had no hurricane survival kit and 60% had no family disaster plan (Goodnough, 2006).

Very similar results were obtained in NCCARF-funded surveys of victims of the 2011 Queensland and Victorian floods in Australia, many of whom indicated a preference to use monies from state and federal disaster relief or insurance to build back the same or better but with no thought of reducing future risk (Bird et al., 2012).

3.7   Global risk financing in coming decades

In coming decades, global trends in population distribution, economic development, wealth accumulation and increasing insurance penetration will place significant strain on the ability to absorb economic losses and undertake post-event reconstruction. Musulin et al. (2009) analysed the implications for future global insurance losses and revealed new peak zones likely to emerge in several developing nations due to the projected changes in demographics, wealth and insurance penetration. They note that the rapid projected exposure accumulation was similar to that experienced in Florida between 1950 and 1990. The authors conclude that the future loss levels will have significant ramifications for the cost of financing disasters through the insurance system, both in the new peak zone locations and in the system as a whole. Their results were independent of any anthropogenic climate change effects on future losses.

Importantly, Musulin et al. (2009) refer to three lenses through which loss mitigation activities can be viewed: life safety, protection of individual properties, and management of overall economic impact. While building code development has traditionally focused on the first two, the authors argue that consideration also needs to be given to the current and future potential for large disaster losses in the area where the building code applies. The destruction of a single building can be easily absorbed into the normal building capacity of an economy but the destruction of one million homes by a major hurricane cannot – the required diversion of material and labour to post-event reconstruction from other activities would cause massive stress and disruption.

Musulin et al. (2009) conclude that the economic value of loss mitigation must reflect the expected cost of risk transfer over the lifetime of the building. Since the cost of risk transfer is affected by the aggregate level of risk in an area it can change if the surrounding area were subject to significant population growth and wealth accumulation. Risk reduction should therefore also target areas of high potential future growth.

3.8 Integrating the financial management of disasters as part of a national strategy

In the aftermath of the very destructive 2004/05 US hurricane seasons, increasing the country's resiliency to natural disasters was destined to become a national priority in the US. As other crises occurred locally and abroad, attention was directed away from this issue, the question of how to best organise financial protection and risk reduction against future hurricanes remains largely unanswered.

Other countries including Australia that have suffered disasters are faced with similar questions. Outside of the OECD countries, developing countries have started to think about these issues. In many cases, populations are growing fast and assets at risk have increased significantly as a result of decades of economic development. The insured losses and economic disruption experienced in the 2011 Thailand floods was an indication that exposure in the developing economies in Asia can have significant implications on the insurance industry and the diversification of risk.

People and businesses are turning to their governments and the private sector for solutions. These solutions will be sought in the form of micro-insurance (well-developed in India and several African countries today), strong government participation (as is the case in China), traditional insurance, or the transfer of catastrophe exposure directly to investors on the financial markets e.g. Catastrophe Bonds (Michel-Kerjan and Morlaye, 2008). Section 5 of this report will examine some of these instruments. Here we simply make the point that each country will have to define and select what solutions make the most sense given culture, current development of its insurance market, risk appetite and other national priorities. These solutions will also evolve over time as a response to the occurrence of (or absence of) major catastrophes. Higher climate variability and increasing exposure means that the financing of disaster risks and long-term disaster mitigation planning must become a critical element of the national strategy in many countries to assure sustainable development.

3.9 Conclusions

Peer-reviewed studies into the economic impacts from natural disasters now span many parts of the world. What is evident from this scholarship is an increasing trend in the cost of natural disasters. While the main drivers of this increasing trend are demonstrably socio-economic factors, an anthropogenic climate change contribution cannot be ruled out, although the literature suggests that its influence is currently small in the context of societal changes and the large year-to-year volatility in the impacts. Moreover it may be decades to centuries before the impact of the climate change on disaster losses caused by extreme weather – tropical cyclones, storms, floods and bushfires -- is detectable with any statistical confidence.

The collective research presented here suggests that there is much to be gained in both the short and long term from reducing societal vulnerability to natural disasters. Without efforts to address this, the economic impacts from natural perils will continue to rise rapidly on the back of an ever increasing exposure. This is particularly the case in developing countries where some of the largest growth rates are projected to occur. Financial solutions that encourage vulnerability reduction should be encouraged in an effort to minimise future losses and to improve the resilience of society from threats posed by future climate change.

4. GOVERNMENT INVOLVEMENT IN THE INSURANCE MARKET AND ITS POTENTIAL TO DRIVE CLIMATE CHANGE

4.1 Abstract

This paper addresses the potential for the insurance sector to be a positive actor in helping to reduce this nation's exposure to the risk to property of extreme weather that may be influenced by future climate change. We review the provision of insurance by the public sector in a number of countries and summarize a selection of possible arrangements and the role they play in encouraging the uptake of catastrophe insurance, risk reduction and resilience building. Examples of government involvement in the insurance market – so-called *residual market mechanisms* – were mostly drawn from the US, France, Spain and New Zealand; flood insurance in the United Kingdom and the Netherlands is also briefly examined.

The creation of residual market mechanisms varies between countries as does the hazard profile. Government involvement in catastrophe insurance in the US, for example, has usually arisen in the face of perceived failures of the private insurance market, often following a significant natural disaster causing unmanageable losses to the industry. In the wake of such events, residual market mechanisms have assumed the legacy of inappropriate land use, unrealistic risk assessment and lack of consideration to risk reduction.

Government pools have certain theoretical advantages over the private sector in being able to spread losses across time; being generally exempt from federal taxes on surpluses, and not requiring pricing to reflect either risk or cost of capital. With financial backup or guarantees from the state, they can fall back on resources not available to the private sector. This was the case for the Earthquake Commission in New Zealand after the 2010 and 2011 Christchurch earthquakes. However, with low priority given to risk reduction and political interference often exerted on the premium pricing structure to keep cover in high risk-areas affordable and not be risk-based, residual market mechanisms face the risk of becoming unsustainable.

Insurance policies generally have duration of a single year, a period at odds with the lifespan of a building (~50 years) and the time scale at which impacts on property losses caused by climate change amplification of extreme weather might become measurable. This mismatch makes it difficult for insurers to materially influence adaptation to *future* climate change except through the rigorous pricing of the *extant* risk. This is reinforced by accounting rules that force insurers to take into account losses in the current time period.

At its core, insurance is about the financial management of *uncertainty* and the tools it employs to assess this uncertainty may be more generally useful in reframing the debate over climate change. This debate is currently framed about 'certainties, with climate change sceptics pitted against environmentalists and with each camp equally intransigent. Reframing global climate change as an insurance problem in terms of uncertainty may be a useful construct especially since in financial markets uncertainty has a positive price – the higher the uncertainty, the higher the premium required to replace the outcome of a contingency with a certain one. We assert that most reasonable parties would admit to investing a little in insurance to safeguard the planet

against the worst outcomes. This is certainly the view of the authors and underpins our treatise here.

4.2   Introduction

This study addresses the potential for the insurance sector to be a positive actor in driving adaptation to global climate change, in particular in helping reduce this nation's exposure to the risk of extreme weather that may be influenced by future climate change. This is not a responsibility that the insurance sector can shoulder on its own, however, and therefore we must also consider the regulatory environment, in other words, the role of government, who, by acting in concert with the free market, may be able to promote risk-informed land-use planning and develop risk reduction infrastructure and improved building codes needed to encourage community resilience to extreme weather events. Any reduction in community vulnerability achieved in this manner will have long-term benefits and represent a prudent investment to manage any additional impacts caused by global climate change.

In examining these questions, we scrutinise examples of government involvement in insurance or reinsurance schemes from other countries. These have usually arisen in the face of perceived market failures of the private insurance market, often following a significant natural disaster. The issue has high currency in Australia after large economic losses caused by flooding in Queensland and Victoria in 2011 and widespread criticism of insurers whose policy covers excluded damage due to riverine flood (van den Honert and McAneney, 2011). The flooding was followed soon after by the landfall in Queensland of Cyclone Yasi, both events coming on the back of a series of large insurance losses due to severe weather in recent years and following an extended period of relatively benign weather (Crompton and McAneney 2008; Crompton, 2011).

Examples of government involvement in the insurance market are drawn from the US, Spain, France, and New Zealand. We also briefly cite experience from the Netherlands, United Kingdom and Fiji. Rather than exhaustively documenting the attributes of each scheme, of which there are even more than those examined here, our aim is to explore a range of different structures and assess their capacity for driving social change. We note that none of these government insurance arrangements were motivated by a concern for the likely impact of anthropogenic climate change on natural catastrophes. Our consideration of extreme weather impacts is restricted to perils likely to cause material property damage, in other words, tropical cyclones, storms (including hailstorms), floods, and bushfires. We do not consider rising temperatures and sea levels even though their projected increases are more firmly constrained by climate models (IPCC, 2012).

It needs to be clearly understood that risk as seen here is a function of three components: the *likelihood* of the physical *hazard* in terms of magnitude or intensity at a given location; the spatial distribution of buildings or infrastructure and their values subject to the physical hazard, i.e. the *exposure,* and the *vulnerability* of assets to the hazard, i.e. the extent of damage caused if impacted by a natural hazard of a given intensity.

Figure 1 shows in schematic form the relationships between these variables, relationships which underpin catastrophe loss modelling now routinely undertaken by the insurance sector and which will be referred to in later discussion.

Risk assessment also has behavioural dimensions (e.g. Slovic, 1999) but these are not considered here.

This chapter -- Section (4) -- is structured as follows. We begin by briefly reviewing the basic tenets of insurance and reinsurance in relation to catastrophe risks. This is followed by a brief summary of the general features of government involvement in the provision of catastrophe risk insurance. Sub-section 4.5 then considers the various residual market mechanisms, including for completeness, the California Earthquake Authority (CEA) and the New Zealand Earthquake Commission (EQC), even though geophysical hazards are not influenced by global climate change. This examination is perforce complex and *inter alia* involves consideration of legislative changes that have influenced the evolution of some of these schemes. Sub-section 4.6 offers a distillation of the key points about the degree to which any of the schemes examined have been successful in driving behavioural change and reducing risk to communities, while Sub-section 4.7 provides a general discussion of the results. The chapter concludes with some implications for the degree to which such schemes might also be agents for dealing with additional threats bought on by global climate change
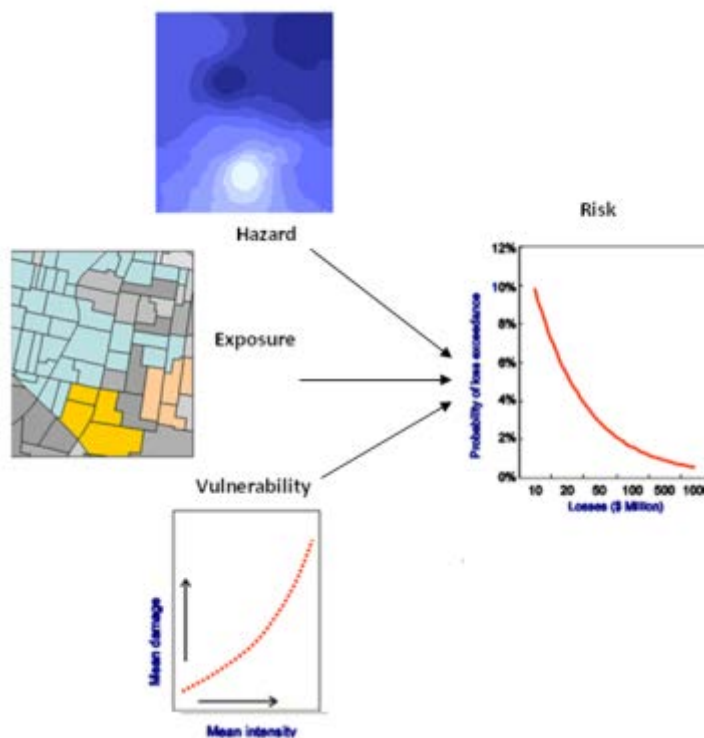
Figure 3: Schematic of catastrophe loss modelling

4.3   Principles of insurance

This discussion that follows is largely drawn from Roche et al. (2010) and Musulin (1997). In short, insurance is purchased by an individual or company as protection against the risk of financial loss due to uncertain events. It is a mechanism that makes the cost of managing risk more affordable for everybody through sharing the risks and the reduction in uncertainty resulting from this. An insurer takes on this risk in return for a premium, and promises to pay an agreed amount in the event of a loss. In other words, the uncertainty of a loss is replaced with the surety of an agreed payout.

Insurance is based on the principle of statistical independence, with two events said to be independent if the occurrence of one conveys no information about the occurrence of the other. Mathematically, two events (A and B) are said to be independent if and only if:

$$P(A \cap B) = \Pr(A)\Pr(B) \qquad\qquad (1)$$

By way of example, let event A be 'car accidents' and event B be 'height of tide'. We may assume that A and B are independent, since car accidents are not determined by the state of the tide. Additional events can be added into equation (1) to represent independence among three or more events.

An insurer will have a portfolio comprising a large number of insured assets or policies. By increasing the number of policies within the portfolio (N), an insurer's uncertainty in the expected losses is reduced. This outcome is described by the Central Limit Theorem, which states that if a random experiment is repeated a large number of times, then the variance around the mean of the random variable of interest decreases with the number of trials (formally as $1/\sqrt{N}$) (Vose, 1996)[1]. In other words, as the number of policies within an insurer's portfolio increases, the mean or expected annual company losses (claims) arising from a given hazard (say structural fires, car accidents or theft) becomes increasingly predictable.

Natural disasters contravene the basic tenets of independence with portfolio losses being both spatially and temporally correlated over a large geographical footprint. This leads to potentially unmanageable losses for the insurer. To avoid this outcome, insurers transfer most catastrophe risk to international reinsurers who in turn diversify their risks on a global scale. In essence, the reinsurers provide insurance companies with protection from losses using the same principles as insurance companies exploit for dealing with individual risks. Globally natural hazard events are assumed to be uncorrelated: a hurricane making landfall in Florida is assumed to be independent of an earthquake in New Zealand or a hailstorm in Sydney. Diversification across geographically uncorrelated areas allows a reinsurance company to reduce the overall coefficient of variability of its claims and thus its losses become more predictable. Again this diversification works better if there are similar sized risks spread across different regions of the world and this is why some US risks, exposure to US hurricanes, for example, pose special difficulties for reinsurers.

It makes sound business sense that insurance (or reinsurance) will only be offered if an insurer can assess the probability of an event occurring and the likely losses given such an event. In this way, the insurer is able to minimize premiums to levels that still provide a competitive return to the company. Historically, this was done through a variety of often rule-of-thumb methods that were subject to several critical biases that collectively conspired to yield large underestimates of the loss potential (Musulin, 1997). Musulin (1997) lists some of these biases prevalent amongst insurers of US

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[1] Formally the above assumes that the independent risks are drawn from the *same* distribution with a finite variance. This criterion can often be relaxed: even if the independent variables are governed by different probability distributions, the sum (or mean) will be approximately *Normally* distributed provided no one variable dominates the uncertainty in the sum (Vose, 1996). Nonetheless, the variance in the mean will be lowered if the risks are similar.

hurricane risk prior to 1990: in particular, catastrophic losses were assumed to be 'normal'; population demographics stable, as were insured losses by peril, and that changes to insurance coverage conditions and construction practices did not affect likely claims levels. After a succession of large losses in the late 1980s and early 1990s (notably Hurricane Andrew in southern Florida in 1992 and the Northbridge earthquake in 1994 in southern California), the insurance industry began investing heavily in the development of computer software and modelling techniques (Figure 1) to better manage and estimate their exposure to natural hazard risks (e.g. Woo, 1999; Musulin, 1996, 1997; Leigh et al., 2009; Roche et al., 2010; Okada et al., 2011).

As a result of this improved intelligence it is possible that insurers may choose to withdraw from certain areas deemed to be at very high risk, to reduce the extent of their cover or to only offer cover at rates far in excess of what consumers have been paying in the past[2]. In turn this is likely to lead to a call for greater participation of government in insurance for the most at risk properties[3]. A key aim of this study is to ascertain whether government involvement in the insurance market can lead to behavioral change to reduce risk. In what follows we examine some such schemes after first tabulating key differences between government pools and private companies in offering insurance cover for natural perils.

4.4   In brief: Differences between Private Insurance and Government Insurance Pools

Private insurance systems must prefund all losses -- it is not acceptable to have a loss and then try to collect funds to pay for it after an event; the premium is supposed to be predictive of future losses (American Academy of Actuaries, 2012). *Government* insurance systems on the other hand can raise funds post-event by issuing government bonds or new taxes, for example.

Private insurance systems usually attract taxes on profits, which can mean that earnings on funds needed to pay claims from infrequent events are taxed away because they show up as income in years without extreme events. *Government* insurance systems are not bound by this constraint.

Private insurance systems operating in a competitive market increasingly set prices related to risk; cross subsidies are unsustainable absent government intervention. *Government* insurance systems are not bound by this constraint.

Governments can use the government's sovereign power to compel one group to pay too much in order to provide a subsidy to another.

Private insurance systems can in principal encourage mitigation through premium discounts and underwriting. However, *Government* insurance systems also often dilute

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[2] At the time of writing, Suncorp Group, one of the largest general insurers in Australia, has withdrawn from offering and renewing policies in the town of Roma until satisfactory mitigation efforts have been implemented after the town was flooded three times in two years.

[3] The Australian government, for example, introduced a federal tax in 2011 to help cover the reconstruction costs of the Queensland floods (van den Honert and McAneney, 2011).

the incentives for mitigation found in private systems by subsidizing high risks from low risks or by raising revenue for losses from an unrelated source, like a tax levy.

4.5 Examples of Government involvement in insurance for catastrophe risks

In what follows we describe some examples of government interventions in the (re)insurance markets, with an emphasis on how they came about, how they are managed; how deficits are funded; the degree of political interference in the pricing of premiums, and whether or not they have been effective in reducing the number of people and assets at risk. The majority of these so-called *residual market mechanisms* were established following extraordinary catastrophic events that brought about instability in the insurance market and the withdrawal or threatened withdrawal of certain insurers from that market.

4.5.1 National Flood Insurance Program (NFIP)

Catalyst for creation
Before the establishment of the NFIP program, the response to flood disasters by the US government was to construct flood control infrastructure -- dams, levees and seawalls -- and to provide disaster relief for damages when disaster struck. Development in high-risk areas was not discouraged and there were no incentives to flood-proof properties (Musulin, 2011). A succession of floods from the devastating 1927 Mississippi flood onwards had led to private insurers withdrawing from the market, voicing concerns that catastrophe risk was uninsurable and citing:

- inadequate flood mapping
- risk of adverse selection
- unaffordability of risk-based pricing
- possibility that catastrophic losses could cause insurer insolvencies, and the
- lack of appropriate building codes in flood-prone areas (Czajkowski et al., 2011)[4].

The federally-backed NFIP was created by the US Congress in 1968 in response to the unprecedented cost of federal disaster relief required for victims of Hurricane Betsy in 1965, when 60,000 people were left homeless. This was the first natural disaster in the US to cost more than $1 billion (Grossi and Muir-Wood, 2006) and a repeat of this event, given 2005 societal conditions, has been estimated to cost some $20 billion (Pielke et al., 2008).

Intent of the NFIP
This residual market mechanism was intended to provide cover for flood risk through a nationwide, *not-for-profit* scheme that collected sufficient premiums to cover losses and expenses based on the *historical average annual losses*. The NFIP is administered by the Federal Emergency Management Agency (FEMA) to provide nationwide cover. Rather than create a surplus to prepare for future catastrophe events, NFIP was to depend on borrowing from government to cover future deficits. Homeowners may opt to purchase private insurance and some insurers do offer flood risk cover.

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[4] These same concerns have been raised in Australia recently by the National Disaster Insurance Review (2011) following the Queensland and Victorian floods (van den Honert and McAneney, 2011).

Pricing and Cover of the NFIP

FEMA sets the NFIP terms and conditions and also the pricing. Premium rates reflect the amount of coverage purchased and the building design, age, location (including, if located in severe flood risk areas, whether or not they are elevated) and occupancy of the building.

From its inception, the NFIP did not generally rate by actual risk. This created a system of subsidy for policyholders in high-risk zones that was paid by policyholders in low risk areas. Subsidized insurance rates, however, did not offer sufficient incentive for homeowners to take out insurance or for enough communities to participate in the scheme to collect sufficient premium revenue.

In an attempt to increase NFIP's coverage, Congress passed the Flood Disaster Protection Act of 1973. This included the mandatory purchase of flood insurance as a condition for the granting, renewing or continuation of a loan by federally regulated mortgage lenders when the property and improvements securing the loan were in the Special Flood Hazard Area (SFHA) of a community participating in the scheme (King, 2009; Musulin, 2011). The resulting increase in revenue from premiums, however, was still not sufficient to cover losses due to catastrophic flood events.

FEMA produces Flood Insurance Rate Maps (FIRMs) to identify flood-prone areas, and subsidies are allocated to owners of structures built in high-risk areas before publication of their community's FIRM (FEMA, 2011). Once the FIRM has been issued, the community is brought into the NFIP "Regular Program". Eligibility, however, is conditional on local government ("the community") committing to flood disaster mitigation measures[5] and compliance with the required floodplain management standards (NFIP: https://www.nfipservices.com).

The NFIP provides up to $250,000 in flood insurance coverage for structural damage to residential buildings and $500,000 for non-residential. Contents are covered up to $100,000 for residential properties and $500,000 for non-residential properties. While the federal government underwrites the policies, most are written and serviced by private Write-Your-Own insurance companies. Policies do not cover the living expenses of policyholders who need to move out of their home whilst flood-damage is being repaired (NFIP: www.floodsmart.gov).

On October 1, 2009, the standard deductible of $500 was replaced by a two tier system whereby the deductible for a property built after FIRMs were introduced was doubled to $1000 and the deductible for a property built before the flood maps were created was increased from $500 to $2000.

Features of the NFIP policies include subsidies and deductibles to lower the cost of insurance for eligible high-risk properties, and incentives to undertake mitigation measures such as elevation of properties or flood-proofing (Musulin, 2011).

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[5] Note that the term *mitigation* is used here in its traditional emergency management sense to denote flood levees, and other engineering efforts to protect communities, and not as in the climate change literature where the term refers to the reduction in greenhouse gas emissions.

Funding of the NFIP
Until 1986 the NFIP was part-funded by the US Treasury (the House Appropriations Committee). From 1986 until 2005 it was self-sufficient, with premium revenue as its primary source of funds (King, 2011). The program is not geared to accumulate a surplus and is unlikely to be able to purchase reinsurance. NFIP has to cover high-risk properties and, at the same time, premium rate increases are subject to a statutory cap of 10% and in many cases rates do not reflect flood risk (American Academy of Actuaries, 2011).

To fund a deficit NFIP has to borrow from Treasury. Between 2005 and 2008, FEMA had to borrow from the Treasury to cover the NFIP losses incurred from increased hurricane activity during that period ($21 billion in claims following Hurricanes Katrina, Rita and Wilma in 2005). The borrowing authority had to be increased three times by Congress, initially to $3.5 billion, then $18.5 billion and subsequently to $20.8 billion. By 2009, $19.2 billion was still outstanding (including interest on the loan), a sum which the program does not have the resources to repay. By law, loans from Treasury must be repaid with interest.

Mitigation
Of the three primary functions of the NFIP, providing insurance for flood risk, mapping flood hazards**,** and stipulating minimum requirements for building codes and floodplain management practices in participating communities, two relate to measurement and mitigation of flood risk and damage (Department of Homeland Security, 2013).

The National Flood Insurance Reform Act of 1994 established a program for the provision of grants to communities to undertake measures to reduce flood risk. For policyholders with flood damage who require assistance rebuilding, the NFIP provides up to $30,000 towards the cost of flood-proofing measures to reduce their future flood risk. This coverage forms part of most NFIP standard flood insurance policies (FEMA Library, http://www.fema.gov/library/viewRecord.do?id=1477).

The policies of "Repetitive Loss Properties" (properties that have been the subject of repeated claims since 1978, regardless of ownership) are transferred to the NFIP Servicing Agent's Special Direct Facility (SDF). The SDF is closely supervised with the aim of considering mitigation options for the properties concerned (FEMA: http://www.fema.gov/pdf/nfip/manual200605/20rl.pdf).

Legislation Affecting the NFIP
Major legislative changes were made in 1973, 1994 and 2004 and 2010. In brief these Acts were:
- 1973 - The Flood Disaster Protection Act of 1973: included the mandatory purchase of flood insurance requirement as a condition for the granting or renewing or continuation of loans by federally regulated mortgage lenders when the property and improvements securing the loan were in the SFHA (Special Flood Hazard Areas) of a participating community (King, 2009).
- 1994 - The National Flood Insurance Reform Act of 1994 included the following:
  - authorization of the modernization of flood hazard maps. FEMA was to assess FIRMS every 5 years (American Academy of Actuaries, 2011).
  - Fining of mortgage lenders who were not compliant with the requirements of the 1973 Flood Disaster Protection Act and who did not enforce the requirement for flood insurance before loan approval. The

NFIP Community Rating System was established to encourage community floodplain management standards that exceed minimum requirements (FEMA, http://www.fema.gov/business/nfip/crs.shtm).

   o A pilot program was established to provide financial assistance for mitigation measures for two categories of repetitive loss properties: "repetitive" (following more than two claims payments in excess of $1000 within a 10 year period); "severe repetitive" (following four or more claims of more than $5000; the total claims payout exceeds $20,000; or at least two claims from the building portion of the policy, which together amount to more than the market value of the structure) (Flood insurance Subcommittee of the American Academy of Actuaries, 2011).

- 2010 – The National Insurance Program Re-extension Act of 2010 H.R. 5115, which in addition to extending the operations of the NFIP, uthorized the appropriation of $476 million over 2011-2015 and $5 million for 2016 to establish the Office of Flood Insurance Advocate and for mitigation and outreach programs. (111th Congress, 2010: http://www.gpo.gov/fdsys/pkg/BILLS-111hr5114ih/pdf/BILLS-111hr5114ih.pdf).

After a consensus that the current structure, President Obama on July 6th July, 2012 signed a bill reauthorizing the NFIP for another five years (considered long-term) and introducing further reform measures – the Biggert-Waters Flood Insurance Reform Act of 2012. This Act allowed for the phasing out subsidies for second homes and properties with repetitive losses, making it easier to apply for a FEMA buyout and raising the annual cap on premium increases from 10% to 20%; (http://www.insurancenewsnet.com, July 7, 2012).

Hurricane Sandy struck the East Coast of the US on October 29, 2012. NFIP payouts for flood damage arising from the event are estimated to total between $12 billion and $15 billion, which exceeds the $4 billion in cash and remaining borrowing authority from the Treasury. As a consequence, H.R. 41 was passed by Congress on January 4, 2013 temporarily raising NFIP's borrowing authority to $30.425 billion. On January 15, $5.4 was apportioned through the Disaster Relief Appropriations Act of 2013, H.R. 152, to fund FEMA's Disaster Relief Fund. An amendment to H.R. 152 provided an additional $33.4 billion in disaster funding for long-term recovery and rebuilding. In total, $60.4 billion was appropriated in relief for damage inflicted by *Hurricane Sandy*.

The FEMA website (http://www.fema.gov/national-flood-insurance-program updated 29th March, 2013) reported in the section *Flood Insurance Reform Act of 2012* that the legislation requires the NFIP to raise rates to reflect the true flood risk. Owners of non-primary residential properties in Special Flood Hazard areas, owners of property suffering severe or repetitive flooding and owners of business properties in SFHA areas will face premium increases of 25% per annum until true risk rates are achieved.

4.5.2   *Texas Wind (TWIA, formerly TCPIA)*

Catalyst for creation
The catalyst for the creation of Texas Wind Insurance Association (TWIA) was the withdrawal of private insurance companies from the coastal property insurance market after Hurricane Celia made landfall on Corpus Christi in 1970. Losses amounted to $500 million. (Pielke et al. (2008) estimate the normalised economic cost of Celia under 2005 societal conditions to be $5.6 billion.) In 1971, the 62nd Texas Legislature passed Senate Bill 31 enacting the Catastrophe Property Insurance Pool Act (Article 21.49 of the Insurance Code), to establish the state run Texas Catastrophe Property Insurance

Association (TCPIA). TCPIA was authorized to act as a residual catastrophe insurance pool offering windstorm, hail and fire insurance to properties in designated areas. Like NFIP it was not designed to be profit-making (Kousky, 2011).

In 1997, House Bill 1632 of the Texas legislature renamed TCPIA as the Texas Windstorm Insurance Association (TWIA) and in 2012 in was further renamed The Texas Coastal Insurance Plan Association (TCIPA). For clarity, the entity will be referred to as the TWIA in this paper.

Pricing and cover of the TWIA
All Texas property insurance and casualty companies are required to be participating members of the TWIA pool. The agents are licensed by the Texas Department of Insurance to represent eligible property owners in the 14 coastal counties along the Gulf Coast and parts of Harris County, and acquire quotes, submit applications and file claims for wind and hail insurance on behalf of the TWIA. Binding authority for the policies is conferred on the TWIA itself. Insurer assessments[6] are calculated according to market share and tax credits can reduce payments if members elect to write insurance in high-risk areas covered by the TWIA.

In 1983, damage caused by hurricane Alicia ($7.5 billion in losses normalised to 2005 societal conditions (Pielke et al. 2008)) brought attention to the fact that building codes were not being enforced and many structures failed to comply with minimum specifications.

In 1987 legislation (House Bill (H.B.) 2012) was passed stipulating that eligibility for TWIA insurance cover was dependent on a building either complying with the program's standards and being issued a Certificate of Compliance (WPI-8) by a Texas Department of Insurance (TDI) windstorm inspector or engineer, or it having been insured prior to January 1, 1988 (Grandfather Eligibility). The Windstorm Inspection Program became effective in January 1988 and WPI-8 certificates were issued as evidence that buildings had been constructed, altered or repaired in accordance with TWIA standards.

In 2007 Representative John Smithee submitted a Point of Concern to the Joint Select Committee on Windstorm Coverage and Budgetary Impact, declaring that the rates TWIA charged were "unrealistically low and substantially inadequate", because the:

- approval of rates was subject to political influence -- the ability of the Commissioner (who is appointed by the Governor) to approve rate increases is subject to confirmation by the Senate, something difficult to achieve in an election year.
- approval of rate increases "is constrained by unrealistic and imprudent statutory restrictions not applicable to private insurers". For example: "the Commissioner may not approve an average rate increase in either residential or commercial coverage that is more than 10% from the prior year, unless a catastrophic event has occurred."

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[6]Assessments are charges made to private insurers participating in a residual market mechanism either on a regular basis (regular assessments) to cover operating costs or after an event should losses exceed the capacity of the program to settle claims (emergency assessments).

Smithee recommended that TWIA rates be removed from the political process and set using updated catastrophe modelling to assess the real risk. With access to more reliable data, TWIA should be able to introduce actuarially sound rates rather than relying on historical storm data.

In March 2009, it was pointed out again that although the TWIA was designed as a not-for-profit program and to be the insurer of *last resort*, it was charging unrealistically low rates and therefore competing strongly with the voluntary market (Peacock, 2009). In an attempt to clarify the intended function of the pool, it was specified within the 81st Texas Legislature's House Bill 4409, effective June 19, 2009, that TWIA serve as a residual insurer of *last* resort and not compete with the private market.

The H.B 3, 82nd Legislative Session introduced yet further risk-reduction restrictions and clarifications introduced including:
- the requirement that evidence of flood cover be provided for structures built or structurally altered in some way after September 1, 2009. This requirement applied if the applicant was eligible for NFIP flood cover;
- an Alternative Eligibility program allowing cover eligibility for structures built before June 19, 2009 without the requirement of a WPI-8 but conditional on obtaining Alternative Certification to provide evidence that the structure complies with the Windstorm Building Code;
- an Alternative Certification will be required for renewal of coverage for policies issued after August 31, 2013 and for new applicants from September 1, 2009 and a surcharge of 15% will be added to the premiums of these policies (Texas Department of Insurance, 2012).

Funding of the TWIA
From 1985 the TWIA relied on policyholder premiums and surcharges, and private market reinsurance to cover potential losses. Reinsurance was replaced in 1993 by the Catastrophe Reserve Trust Fund (CRTF) that was established by the state as a fund to accumulate and control the TWIA's surplus revenue and to control the pool's liability for major windstorm losses. The funds are held by the comptroller, outside the state Treasury.

House Bill 2253, 1999, clarified that the original intent of the CRTF was to be a state fund and therefore not subject to federal taxation. The bill, however, stipulated that the Texas Department of Insurance, which held title to the CRTF, could access funds of not less than $1 million and not more than 10% each year from the fund's investment income of the previous year to be used for mitigation and preparedness plans. Another $1 million of the accumulated funds could be used for the windstorm inspection program (WPI-8).

In high loss years (when losses exceed revenue) the shortfall is drawn down firstly from the CRTF accumulated funds. Further capital may be raised by issuing up to $1 billion in Class 1 public securities and outstanding pre-event public securities, which would be paid from TWIA surcharges to coastal property and member insurer assessments. A further $1 billion may be raised in Class 2 public securities of which 30% is to be recovered from insurer assessments and 70% by surcharges on premiums. If necessary, an additional $500 million can be collected in insurer assessments (Texas Department of Insurance, 2012).

On September 13, 2008, only two months after Hurricane Dolly had struck southern Texas, Hurricane Ike made landfall over Galveston, Texas, with winds up to 230 km/hr. Total damage costs amounted to approximately $15 billion. Much of the damage along the upper Texas Gulf Coast was caused by storm surge. TWIA's refusal to pay claims for storm surge damage caused considerable anger.

According to the Hon. Joseph M. Nixon, Senior Fellow of the Texas Public Policy Foundation, TWIA has paid out almost $3.2 billion in losses and settlement of lawsuits as a result of Hurricane Ike and the pool's claims handling. Following the massive catastrophe losses sustained during the three years preceding Ike, and the under-pricing of premiums, there was insufficient surplus to cover the losses and legal costs, and total member insurer assessments amounted to $430 million. To discourage withdrawal of private insurers from the market, $230 million of the assessment is subject to tax credits (Texas Department of Insurance (TDI), 2012).

The TDI, questioning the management of the program, placed the TWIA on Administrative Oversight in February, 2011. The many recommendations to the Joint Windstorm Insurance Legislative Oversight Board board include those below by Bill Peacock of the Texas Public Policy Foundation:

- TWIA become an insurance provider of last resort, offering actuarially sound rates;
- Elimination of prior authorization for rate increases of up to 10% and the removal of a rate increase cap;
- No federal backup to be available;
- The requirement of flood insurance prior to acceptance for windstorm and hail cover by TWIA;
- Removal of restrictions on rating territories thereby allowing TWIA to apply rates on an actual risk basis;
- That TWIA be required to use updated modelling to rate pricing.

In Appendix H of the report, Bill Peacock added:
> *. . . the testimony provided to the committee at the hearing is evidence that the state of Texas should not be involved in windstorm Insurance . . . the state's involvement in windstorm insurance and the way the TWIA system is designed has made windstorm insurance more expensive because the state cannot share risk . . . private insurance companies can cover damage costs by spreading risks over a wider market. [He suggested] eliminating actuarially unsound restrictions in statute and establishing debt-based funding for TWIA . . . support for the purchase of reinsurance . . .and the state should not seek federal solutions for windstorm insurance.*
> (http://www.texaspolicy.com/pdf/2011-TexasWindstormInsurance-CEF-bp.pdf).

As a consequence of the high legal costs being paid by the TWIA, and the numerous recommendations for reform, legislation was proposed which included restriction of future lawsuits. This caused controversy between proponents of the rights of policyholders and on the other hand, those concerned with the sustainability of the TWIA. Amongst the reforms included in the proposed bill were:

- greater transparency (Section 18);
- requirement that TWAI use the claim settlement guidelines of the commissioner (Section 19);
- requirement that TWIA policies require the filing of an insured's claim within a year of the damage occurring (Section 23);

- an actuarial plan for paying claims following a catastrophe with losses expected to be $2.5 billion or more to be submitted by June 1 to the commissioner and other interested parties if TWIA did not purchase reinsurance (Section 36);
- annual catastrophe plan to be submitted in which TWIA will evaluate losses and the process of claims that would be brought about by a 1:25yr, 1:50yr and 1:100yr event within the TWIA coverage area;
- except for specific actions or inactions, TWIA would no longer be liable for an amount other than covered losses except in cases where mismanagement and intention has been proven (Section 2210.572); and
- policyholders may only file suit against TWIA regarding whether denial of coverage was correct (House Bill 3, effective date September 28, 2011 with policy form revision as from November 28, 2011).

In 2011 TWIA purchased an additional $636 million in reinsurance cover for losses that exceed the available CRTF funds plus bonds, effective, June 1, 2011 to May 31, 2012. The reinsurance was purchased from 47 reinsurers worldwide at a net cost of close to $100 million that will be paid from 2011 and 2012 TWIA premiums (Hartwig, 2009).

Interaction of the TWIA with the Private Insurance Industry
Insurer assessments (charges) are a common component of participatory residual market mechanisms in the US. When a residual cannot manage its exposure following a catastrophic event, assessments are issued to participating members who have a statutory liability to cover a percentage of the shortfall. In the case of the TWIA, all Texas residential insurers are required to participate and insurers are assessed according to their market share at the time of the event. If members elected to write insurance in high-risk areas covered by the TWIA, tax credits can reduce assessments.

The TWIA had insufficient accumulated capital to cover losses caused by Hurricane Ike due to massive catastrophe losses sustained during the three preceding years and under-pricing of premiums. According to the Insurance Services Office (ISO), total windstorm damage claims to the TWIA and private insurers following Hurricane Ike totaled 9.8 billion (Hanna, Insurance Council of Texas, 2010, http://www.insurancecouncil.org/news/2010/jan282010.pdf).

Total member Insurer Assessments amounted to $430 million. To discourage withdrawal of private insurers from the market, $230 million of the assessment was subject to tax credits (Texas Department of Insurance, 2012).
Assessments that insurers have been issued to date total:
Hurricane Alicia, 1983 (total assessments $157 million);
Hurricane Rita, 2005 ($100 million);
Hurricane Dolly, 2008 ($100 million);
Hurricane Ike, 2008 ($430 million) (Texas Department of Insurance, 2012).

Mitigation
The TWIA has been enforcing building standards in new and, more recently, older residences. In 1987 legislation was passed establishing the Windstorm Inspection Program and issues pertaining to its compliance have been mentioned already.

Other pertinent legislative amendments include the adoption of the year 2000 amended International Residential Code (IRC) and the International Building Code (IBC) as the building standards for Texas construction, effective February 1, 2003. In 2007, the

Commissioner adopted the 2006 IRC and IBC as amended by the Texas Revisions, which became effective January 1, 2008.

The Texas Department of Insurance has developed a process for obtaining an Alternative Certification for obtaining windstorm insurance in coastal areas. Residential property owners who do not have windstorm insurance through the Alternative Eligibility Program by August 31, 2012, must obtain an Alternative Certification to be eligible for coverage through TWIA. An Alternative Certification provides evidence that a qualifying structural component complies with windstorm building code requirements.

2012 Financial position
The initial balance of the CRTF in fiscal year 1995 was $122,761,482.

In 2005, $65 million was withdrawn to pay losses resulting from Hurricane Rita. TWIA returned a surplus of $30 million to the CRTF that year.

In 2008, $100 million was withdrawn to pay losses resulting from Hurricane Dolly, from a balance in the fund of $468 million.

In 2008 the entire balance of the fund was withdrawn to pay for losses resulting from Hurricane Ike. Four years later, TWIA was still receiving claims from Hurricane Ike.

The TDI called for consultants to be contracted to work with an advisory committee to draw up recommendations to create "a more viable and sustainable organization to support TWIA's objectives of reducing its net exposure and improving service to TWIA's policyholders. The Commissioner, Eleanor Kitzman, has stated that she believed the present structure of the TWIA is unsustainable:

> *… TWIA's market share was 17.9%. In 2010, it had more than tripled to 57.2% and it continues to grow… With no other significant source of funding to pay claims, this growth in exposure is an excessive burden on coastal citizens.*

On July 1, 2008, TWIA had 247 open claims; 90 days and two storms later, it had over 65,000 claims and was simply overwhelmed.

Prior to changes in the funding structure, TWIA had funded Ike losses to approximately $2.1 billion through a combination of cash on hand, monies held in the Catastrophe Reserve Trust Fund, member company assessments, and reinsurance. However, TWIA currently estimates that Ike losses and litigation ultimately will cost more than $2.5 billion. Paying for the losses and litigation expenses over and above the $2.1 billion TWIA had funded in 2008 has inhibited the Association's ability to accumulate reserves for the next major storm event in the Catastrophe Reserve Trust Fund. As a result, TWIA estimates that its current $3.1 billion ability to pay claims is sufficient to fund a 1:60 year event, whereas a 1:100 year storm could result in TWIA losses exceeding $4.5 billion (Texas Windstorm Insurance Association, 2012).

4.5.3 Florida – Hurricane Windstorm Coverage - FWUA; JUA; Citizens and FHCF

The Florida Windstorm Underwriting Association (FWUA)

Catalyst for creation of the FWUA
The need arose for the first residual market mechanism in Florida in the late 1960s when the private insurance market was showing reluctance to insure residential property in hurricane-prone southern Florida. With mortgage finance conditional on homeowners holding insurance cover, those who were being refused coverage because they lived in high-risk areas were at risk of mortgage default. State Legislature responded to the crisis in 1970, by enacting Chapter 70-234, mandating insurers participate in the first residual market mechanism covering catastrophic windstorm events in Florida, the Florida Windstorm Underwriting Association (FWUA), governed by a board comprising insurance company representatives (Mittler, 1997).

The aim of the program was to ensure affordable windstorm coverage in high-risk areas, particularly for property owners located in a narrow band of the Florida coastline prone to severe wind damage, including the Florida Keys. With the pooling of windstorm damage losses in the designated high-risk areas by the state-run entity, it was presumed that private insurers would be more likely to provide coverage in those areas for non-windstorm hazards.

Pricing and Cover of the FWUA
Premium rates were set by the board, with approval required from the Department of Insurance (DOI). Rates were intended to raise sufficient funds to pay all anticipated claims. Administrative costs were to be covered by the issue of regular assessments on property insurers, based on their exposure. Rates charged by the entity were low, not risk-based, and as a result there was no discouragement of development in areas of high risk (Mittler, 1997).

During the years leading up to Hurricane Andrew in 1992, annual increases in property insurance rates were authorized by the DOI. Nevertheless insurers and regulators alike were basing estimates of risk and potential losses on faulty assumptions and data because they did not have modelling tools available at that time. They were measuring historical frequency, location and intensity data over a relatively short period of time -- the previous 40 years -- and did not take into account that the period from 1960 to 1987 had a relatively low incidence of hurricane activity. Importantly their risk calculations did not take into account changing demographics resulting from large numbers of people leaving low risk areas and moving to coastal and riverside locations bringing higher population and wealth growth in those vulnerable areas (Musulin, 2011).

Unrealistic perceptions of potential losses and fierce competition between private insurers for market share led insurers to take on increased exposure in high-risk areas and price premiums too low. Consequently premium income had failed to accumulate sufficient surpluses to manage future major catastrophe losses. By 1992 Florida's weighted-average rate for a property valued at $75,000 was as low as $338; by 1995 and after Hurricane Andrew, premiums increased progressively 65% (Insurance Services Office, 1994; Musulin, 1997).

According to Insurance Commissioner Tom Gallagher (1994):
> *We used to get filings where the indications called for a 25% rate increase, and yet the company would only ask for 10%. It was a race for market share.*

Interaction of the FWUA with the Private Insurance Industry

With surpluses dwindling due to under-pricing and a reduction in policy take-up for the previous two years, the insurance industry was grossly undercapitalized when Hurricane Andrew struck in 1992, causing an unprecedented $15.5 billion in insured losses and total economic damages exceeding $25 billion. (According to Pielke et al. (2008), the economic cost of Andrew normalised to 2005 societal conditions is $57.7.) As a consequence the insurance industry in Florida was in turmoil, facing unmanageable losses. Twelve companies became insolvent, unable to settle more than $400 million in claims.

The Florida Insurance Guaranty Association (FIGA), with insufficient resources to cover the shortfall, was forced into a special bond issue and the result was that assessments were passed on the policyholders for many years (Musulin, 1997).

The remaining insurers were planning to cancel or refuse to renew homeowner's policies; amongst the reasons they gave were:

- realization (through better risk modelling) that the exposure was higher than previously thought
- lack of capital following Hurricane Andrew payouts
- extent of assessments payable to the Florida Insurance Guaranty Association (FIGA) to cover the claims liabilities of companies liquidated after Hurricane Andrew[7]
- exposure to future assessments
- pricing concerns, and
- concerns of a possible down-grading by rating agencies (Kunreuther and Roth, 1998).

In response to the insurers' intentions to cancel policies and refuse to renew existing ones, the state granted the insurance commissioner power to enact emergency rules and regulations to bring some stability to the market and prevent withdrawal of coverage from the state.

Creation of the Florida Property and Casualty Joint Underwriting Association (JUA)

Reasons for creation

The need for JUA arose because of the difficulties experienced by homeowners who had property damaged in Hurricane Andrew and whose insurers had become insolvent. 27 emergency rules were filed following Hurricane Andrew. Those most relevant to our present discussion were 4ER92-15 (October, 1992) which established the JUA (Florida Property and Casualty Joint Underwriting Association) as a temporary program to expand coverage. Cover was limited to residential properties that had been damaged by Hurricane Andrew and where the property owner had purchased insurance and was

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[7] This means that the FIGA can charge insurance companies additional sums if FIGA's loss experience is worse than had been accounted for in the premium or, as in this case, to cover claims liabilities for companies that went into liquidation after Hurricane Andrew. This additional premium would ultimately be passed on to policyholders.

planning repairs but could not secure settlement of the claim due to insolvency of insurer. Limit to JUA cover was 6 months or completion of repairs.

House Bill 33A (Special Session "A") ratified the emergency measures to take effect on December 15, 1992, including:

- Activation of the JUA: JUA was to be an insurer of *last* resort for those unable to obtain coverage from the private market. The bill included the legalization of the emergency measures enforced by the DOI, and authorization for the JUA to insure unrepaired properties damaged by hurricane Andrew
- Authorization of the issue of up to $500 million in tax-free municipal bonds to cover the FIGA shortfall for unpaid claims to insolvent insurers. The bonds were to be funded from insurer assessments of 2% of property and casualty premiums, which could be passed on to policyholders
- All residential property insurers were mandated to participate in the JUA program and be liable for deficits.
- Pricing was to be set at above market rates
- Funds for JUA were accumulated from premiums and member insurer assessments.

More regulation in respect of JUA
Prior to expiry of the emergency rules, on February 15, 1993, the DOI imposed a 90-day extension on the moratorium and initiated a study on the establishment of a new tax exempt catastrophe fund to provide reinsurance in order to encourage property insurers to remain in the Florida market. At Special Session "B", May 24-28, the moratorium was further extended "for a limited time" (Mittler, 1997).

Attempts were made to "depopulate" the growing FWUA insurance coverage by giving credits on assessments if private insurers elected to write policies in areas of FWUA high-risk exposure. Two insurers were paid cash bonuses to take over some of the JUA's and FWUA's coverage. Nevertheless, the exposure of the two pools increased and their under-capitalization remained a problem.

At a further Special Session in November 1993, a phase-out of the moratorium was recommended with the restriction that an insurer could cancel or fail to renew no more than 5% of homeowner policies until November 1995; catastrophe loss modelling would be utilized to assist actuarially sound pricing; pricing would also reflect mitigation measures undertaken; and policies would include replacement cost (Mittler, 1997).

Creation of a Reinsurance Fund – The Florida Hurricane Catastrophe Fund (FHCF)
A recommendation for a new reinsurance fund, the Florida Hurricane Catastrophe fund (FHCF) was also put forward at the November 1993 Special Session. This fund was subsequently created by the State Board of Administration to provide state-run, low-cost catastrophe reinsurance to provide property insurers with partial cover for future hurricane losses.

The FHCF was in fact the first program of its kind to be granted tax exemption for funds accumulated specifically to cover losses from future catastrophe events. Property insurers would receive reimbursement from this fund of up to $15 billion if hurricane losses exceeded $4.5 billion. The amount of reimbursement would be subject to the

accumulated surplus and borrowing capacity of the fund at the time, the market share of individual insurers, and their choice of deductibility (45%, 75% or 90%).

The primary source of funding was income from premiums paid by private residential property insurers. Should the fund's accumulated surplus be exhausted as a result of catastrophe event losses, additional liabilities would be financed through assessments, revenue bonds or by loans from other private financial sector markets.

Pricing of premiums was based on insurers' risk exposure and the rates that were one quarter to one third of those charged by the private reinsurance market (Hartwig and Wilkinson, 2005).

As at 2011, according to KPMG's Florida Hurricane Catastrophe Fund, Combined Financial Statements and Other Financial Information, June 30, 2011, FHCF had assets and liabilities as follows:

Total assets:	$10,850,094,000
Total liabilities	$6,120,776,000
Total net assets:	$4,729,318,000
Net premium revenue in 2011:	$1,308,877,000

Interaction of the FHCF with the Private Insurance Market
It was mandatory that all Florida residential property insurers participate in the FHCF program. The reinsurance premium could be included in the rates insurers charged their policyholders or collected as a surcharge on premiums.

The disadvantage of mandatory participation in the program was that it encouraged the continuation of undercapitalization on the part of insurers rather than their seeking investor capital to accumulate their own surpluses. The low rates required the state to issue assessments and borrow from the financial markets to cover future catastrophe losses. This has been necessary three times, twice in 1995 ($13.1 million for Hurricane Opal and $47.2 million for Hurricane Erin), and $2.3 billion for the four hurricanes that struck Florida in 2004 (out of total insured losses of $21 billion) (King, 2005).

Creation of "Citizens" - merger of FWUA and JUA

Reasons for creation
Since 1996 there had been discussion on the future of the FWUA and JUA programs. It was recognised that there was a growing need for a residual market mechanism providing windstorm cover in Florida, and that the TWUA and JUA were not large enough to sustain much higher levels of exposure. Neither had been instigated on a permanent basis and consideration was given to creating a larger and more permanent residual market mechanism.

In 2001, the Department of Insurance proposed that to achieve a tax-exempt status and issue tax-exempt securities, the two residual insurers (FWUA and JUA) should be merged into a single entity, to be named the Citizens Property Insurance Corporation ("Citizens"). If a tax-exempt status were achieved, tens of millions of dollars would be saved each year on accumulated income. If tax-exempt securities were authorized, the cost of long-term borrowing would be decreased leading to a possible savings of hundreds of millions of dollars (Committee on Banking and Insurance, 2001).

Debate followed on the merits and disadvantages of the proposed merger. In the end arguments of efficiency gains and lower administrative costs were important factors in bringing about a merger of the two pools. In May 2002 the legislature combined the FWUA and JUA to create one tax-exempt entity: the Citizens Property Insurance Corporation, known as "Citizens." All private insurers were required to participate in the program.

Citizens is funded by premiums, regular assessments on insurers, government and agency securities, corporate bonds, municipal bonds, and private sector securities. Shortfalls would be covered by policyholder surcharges and emergency assessments.

Pricing and Cover of Citizens
Citizens continued the practice of charging below actuarially sound[8] prices and insurers had to keep rates at unrealistically low levels to compete. The program was undercapitalized and subsequent losses would be passed on to policyholders through post-disaster assessments. Thus all insurers operating in Florida became liable for funding future deficits incurred by the program. According to the Congressional Budget Office in 2002, "the current low prices of the Florida programs do not represent the full cost of the insurance" (Congressional Budget Office, 2002).

In October 2005, it was necessary to issue insurers a 7.8% assessment to cover the losses incurred by the four hurricanes that made landfall that year. Following Hurricane Wilma, when Citizens' losses amounted to $1.4 billion, the board sought a 16% increase in premiums for high-risk properties.

In 2007 rates were required to be actuarially sound (Government Accountability Office (GAO) 2007). Despite this requirement, rates were soon decreased and frozen until 2009 and eligibility requirements relaxed: homeowners were permitted to purchase a policy from Citizens even if they had not been denied private insurance coverage, on the condition that the cost of a comparable policy was more than 15% higher than a Citizens policy. Properties within 2500 feet of the coast were exempt from complying

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[8] The term *actuarially sound* is defined specifically in some circumstances, but more often it is understood to mean reasonable and consistent with generally accepted actuarial principles and practices. Evaluations of what constitutes an actuarially sound rate and/or program often are focused on the estimation of losses and/or the cost of financing large losses. For example, the prospective estimation of catastrophic losses might utilize a complex computer model rather than long-term historical averages. As another example, the NFIP has been considered by many as actuarially unsound because, in addition to the issues noted above, there is no provision in the rates for the cost of capital. As noted above, NFIP losses above its capital or reserve levels are funded by borrowing from the U.S. Treasury and are intended to be repaid over time by policyholder premiums. While not all publicly based catastrophe programs rely on outside sources of funding (e.g., taxpayer dollars or assessing a broader policy base), when they do, additional examination is needed to evaluate actuarial soundness (American Academy of Actuaries, 2012).

As it applies to government pools, the issue of *actuarial soundness* is very complicated because of assessments and bond issuances, the payment of which is based on the market share at the time of issuance and which may not correspond to the ongoing position of the company.

with building codes and rate adjustments were postponed until 2012. As a consequence Citizen's coverage doubled[9].

In 2008, a task force report recommended that Citizens revert to being an insurer of *last* resort and that rates be increased over time starting from the date of expiry of the rate freeze (December 31, 2009). Average annual increases were to be capped at 10% state-wide, 15% territory-wide, and 20% for any individual policyholder (Citizens Property Insurance Corporation Mission Task Force 2008). New legislation (Senate Bill 1714, filed April 2011) was debated in early 2012.

Applicants for wind cover with Citizens must have current flood insurance cover, unless they were tenants or condominium unit owners above the ground floor, not eligible for cover by NFIP or were owners of a mobile home located more than 2 miles from open water.

The income of the corporation and interest on the debt obligations issued by Citizens are to be exempt from federal income taxation.

New changes include the following:
- Effective 1st January, 2012 a structure with a replacement value of $1 million or more is no longer eligible to apply for cover. If cover was in place on 31st December, 2011 cover would continue until the end of the policy term.
- Effective 1st January, 2014, a structure insured in the personal lines account with a replacement value of $750,000 or more will not be eligible for cover. Cover in place on December 31, 2013 may continue until the policy expires.
- Effective 1st January, 2016, a structure insured in the personal lines account of the corporation with a replacement value of $500,000 or more will not be eligible for cover but cover in place on 31st December, 2015 may be covered until the end of the policy term.
- Any property for which the permit was issued on or after June 1, 2011 to be built seaward of the coastal construction control line is not eligible for coverage by the corporation.
- A personal lines residential structure located in the "wind-borne debris region" as defined in s 1609.2, International Building Code (2006) (and with an insured value of $750,000 or more is eligible for cover by Citizens. However, the corporation may charge an appropriate surcharge unless the structure has opening protections such as shutters or protections on all openings, as required under the Florida Building Code for a newly constructed residential building in that area.
- If necessary (when the projected deficit in a particular year exceeds 6 percent of the aggregate state wide direct written premium for the subject lines of business for the prior year), regular assessments shall be levied on assessable insurers and insureds of up to the greater of 6% of the deficit or 6% of the state-wide direct written premium for the subject lines of business for the prior year.

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[9] According to Weinkle (2012) the average price for a Citizens policy in March 2012 was $2,067, $275 less than it was in 2003, and $882 less than in 2009 (after adjusting for inflation and changes in GDP); the average number of policies active in 2011 was 1,400,000.

- If the deficit should exceed that amount emergency assessments may be levied for as long as it takes to cover the deficit.
- Bonds may be issued and the corporation may take all actions needed to facilitate tax-free status including formation of trusts or other affiliated entities.
- Rates for coverage are to be actuarially determined and not competitive with the private market. The corporation recommendation must include a catastrophe risk load, a provision for taxes, a market provision for reinsurance costs and an industry expense provision for general expenses, acquisition expenses and commissions
- A rate increase shall be added each year for each residential line of business, not exceeding 20% by territory and 25% for any individual policy, excluding coverage changes and surcharges.
- This will be effective until January 1, 2015 and does not apply to rates for sinkhole coverage or costs for private reinsurance, if any.

Financial positions of Citizens
Citizens' financial resources include insurance premiums, investment income, operating surplus from prior years, Florida Hurricane Catastrophe Fund (FHCF) reimbursements, private reinsurance, surcharges assessments. The total (All Accounts Combined), as reported by the Florida Senate on March 15, 2013, is as follows:
- Policies in Force: 1,284,801
- In Force Premium: $2,724,363,117
- Total Exposure: $405,714,152,265

Nearly half of this exposure is in the coastal account which issues wind-only policies for personal residential, commercial residential and commercial non-residential in limited eligible coastal areas. As of December 13, 2013, Citizens will have a surplus of approximately $6.34 billion following nearly several seasons without a major hurricane making landfall on the Florida Coast. (At the time of writing (March 2013), no hurricane of intensity Category 3 or above has made landfall on the US coastline for 7 seasons, the longest 'drought' in the history of recordings.)

For the upcoming season Citizens will have purchased $1.75 billion in private reinsurance coverage and $5.73 billion in mandatory layer reinsurance from the FHCF. For Citizens' probable maximum loss (PML) from a 1-in-100 year event in the 2013 hurricane season is estimated to be $20.42 billion.

4.5.4   California Earthquake Authority (CEA)

Catalyst for creation
The CEA was established by the California legislature in 1996 in response to a crisis in the availability of homeowner insurance cover following the Northridge earthquake, a magnitude 6.7 earthquake that struck the San Fernando Valley, northern Los Angeles, causing 72 deaths on January 17, 1994. Direct economic losses amounted to around US$ 47 billion, or about $87 billion normalised to 2005 conditions (Vranes and Pielke, 2009). Insurers were liable to pay claims of $15 billion, despite having received a mere $3.4 billion in premiums over the previous 25 years (Kousky, 2011).

Before the Northridge earthquake struck, approximately a third of homeowners in the affected area had earthquake cover. Prospective homeowners were not required to take out earthquake insurance to obtain home mortgage finance and mortgage lenders tended to spread their risk geographically. (Note the contrast between this situation and that in respect of windstorm and flood reviewed in the previous sections). Insurers had

adopted the same principle, by spreading their risk over lines of business and nationally. Consequently losses in high-risk areas would be subsidised by all policyholders. Despite the fact that residential insurers had been required to offer voluntary earthquake cover in writing to all prospective policyholders since 1985, there had been a decrease in take-up during the 1990s (Petak and Elahi, 2000).

In 1995, in an attempt to increase earthquake insurance take-up, the "mini-policy" was introduced, and property insurers in California were required to offer cover for a minimum of 15% of insured value (depending on their deductible) and for structural damage only. Insurers however had become increasingly reluctant to continue their earthquake exposure. They voiced concerns that should a major earthquake event hit central San Francisco or Los Angeles, they would be threatened with bankruptcy, based on the magnitude of claims they had paid out following the Northridge earthquake and the lack of capital remaining in surplus (Jaffee and Russell, 2000).

Attempts by insurers to improve sustainability by increasing rates had been met with opposition by homeowners and lack of support from the state insurance commissioners and consequently they announced their intention to withdraw from the homeowner insurance market in California.

Much discussion and negotiation between the state legislature and insurers ensued in an attempt to prevent a crisis in cover availability. Rather than pay an "exit tax" and to avoid the requirement of the rider offering earthquake cover in their own policies, 70% of private homeowner insurers agreed to transfer funds and participate in the California Earthquake Authority (CEA. This was established by the legislature in 1996 (Jaffee and Russell, 2000).

The CEA intended to operate as a tax exempt, not-for-profit, but largely privately funded insurance pool. The CEA was restricted to covering seismic damage. Participation by private insurers was not mandatory, but those who declined were required to offer earthquake cover for buildings and contents in their homeowner policies. CEA Policies were sold and managed only by member insurers.

Pricing and Cover of the CEA
CEA resources comprise income from premiums, insurance company contributions on becoming participating members, policyholder assessments and post-event industry assessments, returns on invested funds, borrowed funds and reinsurance. There was no recourse to state government back-up should an event push the program into deficit and with liquid assets of only $357 million, the CEA had insufficient funding to offer full cover to policy holders. It therefore adopted its own "mini-policy" offering 50% cover. The options were expanded in 1999, when policyholders could opt for higher coverage limits at five different levels (Jaffee and Russell, 2000).

The resources available to the CEA were expected to provide capacity to settle the claims of 50% of earthquake cover arising from two events of the magnitude of the Northbridge earthquake, i.e. a combined event loss of approximately $7.2 billion. If the accumulated surplus was insufficient to cover losses, policyholders would be issued a 20% surcharge and member insurers would receive assessments up to a total member contribution of $3.66 billion. If a shortfall remained, claims would be settled only when sufficient income from premium payments became available. Private insurers were not authorised to recover the cost of assessments by issuing policyholders surcharges (Jaffe and Russell, 2000).

Premiums from the outset were intended to be actuarially sound, but modelling used by the CEA calculated earthquake probability by magnitude and geographical location, limiting rating zones to only 19, rather than to individual properties. (Rating individual properties would have been possible and allowed for better risk-based pricing, but would have been more costly to the program.) This smoothing of risk led to some policyholders in low-risk areas subsidising those with high earthquake risk, and at the same time encouraged development in high-risk areas and increased the risk of moral hazard by not rewarding or offering any incentives for home owners' mitigation efforts.

Initially CEA members covered 22% of the total policy take-up rate of 36% of homeowners in the state. This figure dropped when "mini-policies" were offered to CEA policyholders in low-risk areas because of cherry picking by non-CEA insurers at lower prices and new entrants to the market offering lower deductibles and higher coverage limits.

Meanwhile, political pressure brought about reduction in rates and the consequences to the CEA were higher exposure and decreased sustainability. The CEA was obliged to increase policy options with higher coverage limits set at five different levels. Exposure amounted to $162 billion and income from premiums totalled $400 million rather than an expected $1 billion, leaving the CEA increasingly vulnerable to catastrophic losses (Jaffee and Russell, 2000).

In 2005, only 15% of California homeowners had earthquake coverage. Under pressure from the Insurance Commissioner, who was attempting to lower rates and attract more policyholders, premiums were adjusted to decrease the state-wide contribution by an average of 22%, although some policyholders had increases of 15% in their premium rates.

An increasing percentage of property owners in the state of California remain unwilling to buy any earthquake insurance, due to the perception that premiums are too costly, especially considering the limitations of the cover. Many believe that in the event of a future earthquake, their personal losses are unlikely to exceed the 15% deductible (Petak and Elahi, 2000).

Despite the low take-up rate, legislators remain reluctant to mandate compulsory cover. Consequently a large proportion of the total losses caused by future catastrophic earthquake events would fall back on the taxpayer when government is forced to provide disaster relief, or, with disaster relief programs reducing in line with federal cutbacks, the victims may have to absorb more of the loss themselves (Petak and Elahi, 2000).

Reliance on disaster relief also encourages the current trend of development in high-risk areas and the lack of incentives for mitigation and ever-increasing losses (Kousky, 2011).

Funding of the CEA
In August 2011, the CEA announced the completion of its first transaction allowing the pool to obtain lower cost reinsurance from the capital markets in addition to the $3 billion of reinsurance purchased through traditional reinsurers. This was the first earthquake-only catastrophe bond issued without recourse to traditional reinsurers and comprised a three-year contract for $150 million cover (CEA Press release, August,

2011, www.EarthquakeAuthority.com.) A second transaction was announced by the CEA in February, 2012 for a further $150 million cover for three years.

CEO Glenn Pomeroy stated:

> *Successful completion of this second transaction demonstrates CEA's ongoing commitment to diversify and expand its claim-paying resource. A diverse set of risk-transfer tools, combining traditional reinsurance and catastrophe bonds with post-earthquake federal loan guarantees, will help make earthquake insurance more affordable.*

The release also stated that the CEA is continuing to support efforts in Congress to authorize a federal guarantee for CEA's private-market borrowing. The guarantee would save policyholders approximately $100 million per year in premium costs.

Russo and Van Slyke (2012) sum up the seven layers of coverage for the CEA:

- Contribution of participating members on joining the pool, proportionate to market share
- Retained earnings
- Post-event industry assessments. If the second layer is penetrated, insurer assessments may total up to $3 billion with individual companies paying according to their market share
- Reinsurance $2 billion of coverage excess of $4 billion less surplus from income
- Revenue bonds issued by the state up to $1 billion. This would be repaid through policyholder surcharges of up to 20%
- The sale of Catastrophe bonds to financial markets, and
- A second layer of industry assessment of up to $2 billion.

CEA's net assets as at January 2013 were $4,505,782,237
(CEA, 2012, http://www.earthquakeauthority.com/%5CUserFiles%5CFile%5C04-26-2012_GB_Attachments%5CComplete_4-26-2012%20GBmtg.pdf)

Research efforts towards mitigation
Ground motions of more than double those allowed for in the mandatory building code were recorded in the 1994 Northridge earthquake, and formerly unsuspected weaknesses in building practices were revealed including those using wood and steel moment frames (Risk Management Solutions (RMS), 2004; FEMA, 2000). These discoveries led to more appropriate building code standards, the retrofitting of structures, and an increase in the use of hazard mapping.

The CEA is a major sponsor of the Working Group on California Earthquake Probabilities, a multi-disciplinary collaboration of scientists and engineers that has released three revisions of the Uniform California Earthquake Rupture Forecast (UCERF) – the first comprehensive framework for comparing earthquake likelihoods throughout all of California. It provides important new information for improving seismic safety engineering, revising building codes, setting insurance rates, and helping communities prepare for inevitable future earthquakes.

In developing the UCERF, the Working Group revised earlier forecasts for Southern California and the San Francisco Bay Area by incorporating new data on active faults and improved scientific understanding of how faults rupture to produce large earthquakes. It extended the forecast across the entire state using a uniform

methodology, allowing for the first time meaningful comparisons of earthquake probabilities in urbanized areas such as Los Angeles and the San Francisco Bay Area, as well as comparisons among the large faults in different parts of the state (Prof. Paul Somerville, Risk Frontiers, pers. com.).

The California Seismic Safety Commission, the CEA and the California Geological Survey have arranged a partnership to provide technical assistance to the CEA to develop the first update of the UCERF and the Next Generation Attenuation West 2 programs, which are required by loss modelling companies and earthquake insurance companies in California to assess seismic hazards. The UCERF program covers some critical issues observed during recent earthquakes in Chile, China, California, Mexico, Japan and New Zealand. The results from the two projects will be used in 2014 by the United States Geological Survey to update California's part of the National Seismic Hazard Map and will be used to update U.S. building codes (State of California Alfred E. Alquist Seismic Safety Commission, Annual Report for 2012, p7 http://www.seismic.ca.gov/pub/CSSC_13-01AnnualReport.pdf).

Separate from CEA, the CUREE-Caltech Woodframe Project consists of coordinated engineering investigations and implementation activities whose objective is to significantly reduce earthquake losses to wood frame construction. This category of construction includes larger-size apartment and condominium buildings as well as houses; non-residential as well as residential buildings; and both existing and new construction. The project is funded by FEMA through a grant administered by the California Governor's Office of Emergency Services (Prof. Paul Somerville, Risk Frontiers, pers. com.).

4.5.5 New Zealand's Earthquake Commission (EQC)

Creation of EQC

As discussed above, with the exception of nationwide flood cover provided by the NFIP, each state in the US controls its own catastrophe insurance market. With regard to earthquake cover, we have examined the California insurance market, a state-run but privately funded pool of participating member insurers working alongside the non-CEA members of the voluntary market. New Zealand, which is also prone to earthquake and volcanic activity, has taken a very different approach to catastrophe cover. The Earthquake Commission (EQC), formerly the Earthquake and War Damage Commission created in 1945, was established by The Earthquake Commission Act in 1993. The EQC is a government-owned Crown entity and the settlement of valid claims is guaranteed by the government.

The EQC was intended to provide nationwide natural disaster cover (for earthquake, landslip, tsunami, volcanic eruption, hydrothermal activity, storm or flood damage to land, and fire following any of the above events) to all policyholders of residential property insurance in New Zealand.

Pricing and Cover of the EQC

The entity covers replacement value up to $NZ100,000[10] plus Goods and Service tax (GST) for homes, and $20,000 plus GST for contents. Property owners have the option of topping up their cover with private insurance. EQC cover is paid for through a levy added to all private insurer homeowner policies. EQC collects the levies from the

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[10] All costs in this section are in New Zealand dollars.

private insurers and passes the funds on to the Natural Disaster Fund (NDF) to invest on its behalf. EQC premiums are only collected through private insurer homeowner policies; homeowners who do not take out primary residential insurance are not eligible for EQC earthquake cover.

Valid claims are required to be settled within a reasonable time by EQC's Catastrophe Response Programme (CRP), which organizes the resources required to respond to a disaster (EQC, 2009). This requirement was sorely tested by the Moment Magnitude 7.1 Darfield earthquake, Canterbury and on-going aftershocks. The continuing cluster of earthquakes that followed the Darfield earthquake has seriously impacted Christchurch, the major city in the South Island of New Zealand, to the extent that much of the Central Business District is being demolished and will be rebuilt, and large areas of residential property have been rendered unsuitable for rebuilding because of liquefaction. While policyholders are protected by the EQC's government guarantee, the scale of this event has effectively rendered EQC technically insolvent and revealed shortcomings in the organisation's ability to cope and in its interactions with homeowners and private insurers.

When the current EQC was established there was already a large fund available which was generating investment income in excess of revenue from premiums. The EQC's structure and operations were based on the availability of these resources and appeared to be sustainable because the Earthquake and War Damages Commission it was replacing had not purchased reinsurance for its 40 years of operations; instead it had allowed income to accumulate whilst Government provided a guarantee to cover claims should they exceed available funds.

It had not been necessary to call upon this guarantee before the 2010 and 2011 Canterbury earthquakes and numerous aftershocks. A benign period in terms of major seismic activity from about 1942 to 1995 and lack of significant damage from the M7+ earthquakes after that had blinded everybody to the real risks of a major event. It is significant that every active period has produced at least one major disastrous event: the 1855 Wairarapa earthquake; the 1931 Napier earthquake and now the 2010 Canterbury event and its aftershocks.

Issues emerging from the Canterbury earthquakes (2010 - 2011)
Canterbury suffered two related large earthquake events in September 2010 and February 2011, with numerous after-shocks, of which at least 11 have been described as "earthquakes, which the EQC has recognised as giving rise to natural disaster damage" and five of which impacted the insurance sector beyond the EQC "deductable" (Brook, 2011).

The second major event was more devastating than the first resulting in large ground motions in the Christchurch CBD and occurred during the working day. 185 people were killed and Treasury estimates put total financial losses for seismic activity in the disaster area from September 2010 onwards to be around $18 billion, equivalent to 8% of the country's Gross National Product (GDP) (http://www.treasury.govt.nz/reasury website). Few modern cities have been impacted to this degree by a natural disaster and, as a percentage of GDP it ranks as one of the more costly events in history.

Complications have arisen in processing claims relating to the Canterbury earthquakes because the EQC policy is to make payment on completion of repairs to damaged properties. In several instances property damage from prior earthquakes in the sequence had not been repaired when another event struck causing further damage. A

dispute arose between the EQC and claimants with such claims when the combined damage costs surpassed the limit of $100,000 cover for building and $20,000 for contents. The matter was referred to the New Zealand High Court, which found in favour of the claimants: whilst a policy is in force, property remains insured for damage resulting from a second earthquake, and the EQC is liable for full cover for damage caused by both events (Brook, 2011).

Losses from the sequence of earthquakes in the Canterbury region are ongoing and since event losses cannot be aggregated, EQC is liable for the full cost up to the attachment point of its reinsurance cover. This is a very unusual circumstance and in the light of this EQC has seen fit to increase its reinsurance cover to provide available resources to respond to two events of the magnitude of the September 2010 earthquake.

Another problem for insurers, both public and private, has been liquefaction in some residential areas. Originally introduced to cover landslip, damage to residential land within 8 m of the home or out buildings is covered by EQC, as is land within 60 metres of the house that constitutes or supports the main access way, or part of the main access way to the house from the boundary. In some cases where properties have suffered liquefaction, the building is restorable but not on the original land which has now been zoned unsuitable for residential housing.

The government has agreed to pay the former market value for the land but the insurer is only liable for repairs to the building. Many of these homes are of slab-on-ground construction and cannot be relocated, and will eventually have to be condemned[11].

Following the exceptionally high cost of the Canterbury earthquake claims, EQC's levies were increased threefold, from 5c to 15c per $100 of insurance cover, up to a revised maximum of $150 plus GST, effective February 1, 2012. This is effectively a flat rate because it would be hard to find a property in New Zealand valued at less than $100,000 (www.nzherald.co.nz, August 2, 2012).

Private insurers were also faced with a large number of claims as a consequence of the Canterbury earthquakes. (Policy holders may only lodge claims above the EQC cover limits). In response to the possible insolvency of one of the larger insurers, the NZ-based AMI Insurance Ltd, the government announced that a financial support package would be available if the reserves of AMI were completely exhausted before completion of claims settlement: the government would invest up to $500 million of equity in the company, with the right to take over control and ownership. The company has since been taken over by the Australian-based insurer, Insurance Australia Group, making it the largest insurer in the region.

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[11] This has caused a lot of angst since owners of homes originally declared total losses, are now being told by some insurers that the buildings are considered repairable despite the fact that repairs are not permitted on their condemned land. The owners have been told that they can only claim the repair costs which are significantly lower than the total sum insured, payable if the structure itself had been written off. As a result these policyholders will be out of pocket when they rebuild at a new location.

Since the Canterbury earthquakes, several of the major private insurers are no longer writing new policies in Christchurch. Continuing seismic activity makes risk-pricing difficult and so availability of top-up cover has reduced.

 A review of the EQC is planned with regard to the future operations and interactions of public and private insurers in the New Zealand earthquake risk-related market. Questions of subsidies and risk-based premiums or levies are likely to be included in the review and it will almost certainly have to be restructured once the Canterbury earthquake claims have been largely settled.

Funding of the EQC
Prior to the September 2010 earthquake, the National Disaster Fund (NDF) and EQC had reserves of NZ$6 billion, invested in cash ($300 million), global equities ($1.7 billion) and New Zealand government bonds ($4 billion). EQC had purchased $2.5 billion of reinsurance cover. Since the event, ECQ has renewed its reinsurance to cover two events the size of the September 4, 2010 earthquake.

Total claims payouts were initially estimated to be around $3 billion, but with 287,000 claims received to date (The Treasury, 2011), updated estimates, with the inclusion of after-shock damage, amount to over $7 billion. And this is not necessarily the final toll. The total cost will more than exhaust the NDF capacity for settlement of claims.

The Treasury estimated that the threefold increase in levy referred to above, although still not set at risk-based levels, will help cover EQC's operating costs, which have been subsidized by NDF investment income for many years and rebuild the NDF surplus to the $6 billion pre-earthquake level within 30 years (New Zealand Government, 2011).

Premiums are still not set at risk-based level. If these changes are going to reduce the need for government back-up then the levy must be above the risk-based level, since a risk-based level would just pay for reinsurance costs, administration costs, and annual attrition claims. Any accumulation of funds above this level requires a premium higher than the pure risk premium. The statement also assumes no major natural disasters will strike New Zealand in the interim; consequently the EQC has seen fit to increase its reinsurance cover to provide available resources to respond to two events of the magnitude of the September 2010 earthquake.

Research efforts towards mitigation
The post-event investigations into the 1994 Northridge earthquake in California found that the measured ground motions had been double that allowed for in the Californian building code. It revealed that building materials such as pre-cast hollow-core floor units that at that time conformed to the required standard in California in 1994 had been deficient. New Zealand engineers were concerned by the results of the investigation and the University of Canterbury carried out tests on the materials found to be deficient. Their results were reviewed by a technical advisory group and changes in design recommended, which led to the introduction of an Amendment to the Concrete Design Standard, NZS 3101 in 2004. The higher standards were applied to the national Building Code (Cowan et al., 2008).

The EQC has invested over many years in the GeoNet network of geographical recording instruments and software, which provides monitoring and analysis on earthquake, and volcanic activity, landslides and deformation leading to large earthquakes (Cowan et al., 2008). The 2010-2011 Canterbury earthquake sequence

was recorded by GeoNet and the measurements will lay the foundations for better ground motion models.

The EQC also funds various research programs looking at geological risk assessment and mitigation, and encourages homeowners to undertake risk reduction measures to prevent catastrophe damage through public education. However homeowners have been slow to respond. Walker and Musulin (2010) suggest that because of the uniform levy there is no direct incentive through the EQC and no perceived financial advantage to individual householders to mitigate the risk of damage to their properties.

4.5.6 Spain - Concorcio de Compensacion de Seguros (CCS)

Reasons for its creation
The CCS was founded in 1941, following the Spanish Civil War (1936-1939), to indemnify Spanish insurance companies against claims arising from unpredictable events including natural disasters. The entity was established on a provisional basis. In 1954 it was transformed into a permanent state-run institution within Spain's Economics and Finance Ministry. The primary purpose was to provide nationwide cover for extraordinary risks (Barredo et al., 2012).

The CCS is classified as a public entity but has its own legal framework and is subject to the same laws as those regulating the private sector.

The Board of Directors is chaired by the Director General for Insurance and Pension Funds; the program is decentralised with 18 regional committees consisting of independent professionals who are responsible for loss adjustment (Barredo et al., 2011).

The principles of the program are "compensation", "solidarity" and "cooperation", where:
> "Compensation" implies that all hazards are covered in all parts of Spain, regardless of risk, and covered with a uniform premium base.
> "Solidarity" refers to the contribution to the central fund by all policyholders, based on the insurance value of their asset, for the payment of compensation to those who are affected by natural hazard losses.
> "Cooperation" refers to the interaction between the private market and the CCS in the application of the scheme (Consorcio de Compensación de Seguros, 2008).

Pricing and Cover
Extraordinary risks cover is a compulsory component for all prospective policyholders seeking to purchase insurance from private insurers to cover life; fire and perils of nature; motor vehicles (vehicle damage only); property damage and personal accidents (Meneu, 1995). Private firms may offer the extraordinary risk cover themselves but are not legally bound to underwrite it on their own behalf. Most choose to opt out of the risk exposure by adding the CCS surcharge to the pricing of their premiums and transferring collected surcharge monies to the CCS on a monthly basis, less the 5% insurers are authorized to deduct to cover their expenses. All claims are regulated and processed by the CCS (Machetti, 2005).

The CCS surcharges have a uniform base nationwide – 0.08 per 1000 euros of insured value in the case of dwellings and a deductible of 7% (CCS, 2012).

The breadth of the premium base and the resulting growth in revenue surplus, however, has allowed CCS to provide cover for a wide range of natural and man-made perils, including floods, earthquakes, tsunamis, volcanic eruptions, atypical cyclonic storms, terrorist attack and meteorite.

In the case of flood, to date one of the more expensive perils, the cover offered by CCS includes: lake, riverine and coastal flooding, snow and ice-melt and waterlogging, but not rainfall directly on the insured asset or collected on roofs.

Exposure has grown by 700% since the 1970s, mostly through higher insurance penetration and increases in the value and number of insured assets (Piserra et al., 2005).

Prior to 1986 a Declaration of Catastrophe Zone had to be made before flooding losses were covered, but this requirement was modified in 1986 to include any flooding disaster. In 2004 the cover description was further amended to include business interruption (Barredo et al., 2012).

Funding of the CCS
The CSS is required by law to maintain a Solvency Margin, and all profits must be accumulated in this surplus fund. Income is derived from premiums and investment returns on the surplus (Meneu, 1995). Surcharges were initially calculated as a ratio of the premium paid for each private insurance policy. In 1987 that was amended and the insurance value of the asset was used for the calculation (Barredo et al., 2012).

The program is backed by a State guarantee that would cover any shortfall in a high loss year. The CCS surplus, however, has been steadily increasing. By 1995 the State had not been required to provide back-up funding (Maneu, 1995) and by 1999, 1.9 billion euros had been accumulated (Consorcio de Compensación de Seguros, 2008; Paudel, 2010).

The costliest year for extraordinary risk losses was 1983, when flooding in the Basque Country, Cantabria and Navarra caused insured losses amounting to 623 million euro (Barredo et al., 2012).

4.5.7 France – the Caisse Centrale de Reassurance (CCR)

Reasons for creation
The CCR was originally established in 1946 as a traditional reinsurance mechanism that had joined with SCOR (a publicly listed company created in 1969) but had retained its identity and developed over the years to cover a range of risks that vaguely come under the classification of "exceptional". At that time private insurers would not cover natural disasters except for storms and hail on roofs and then after 1981 snow on roofs and earthquake risk to industrial property. Disaster damage was largely compensated by ad hoc government disaster relief payments (Magnan, 1995).

Following major flooding events in late 1981, Act N° 82-600 of July 13, 1982 introduced a scheme for the compensation of damage caused by natural disasters in France, and on August 10, 1982, authorized the CCR to provide state-guaranteed reinsurance coverage for risks specified within the scope of the act. This meant that private insurers issuing insurance policies covering fire and other property damage, motor vehicle damage and loss of business profits were now required to cover the policyholder against direct damage and loss of profits caused by a natural disaster. This combination of private insurance industry, a state-guaranteed public reinsurance and

the Treasury to provide catastrophe cover is known as the "Cat-Nat system" (Marcellis-Warin and Michel-Kerjan 2001). An event has to be declared a "natural disaster" by decree for such cover to be enforced (Magnan, 1995).

Article 1 of Act No. 82-600 describes key principles of CCR, the:
- obligation to include catastrophe cover in homeowner policies
- right of compensation for damage caused by natural disaster
- liability of policyholders to take preventative measures to reduce risk (CCR, 2008).

Initially, CCR cover had been restricted to mainland France, but this limitation was removed with Act No. 89-509 of June 25, 1990 authorizing the inclusion of the Overseas Departments (Territories). Other related changes included:
- Act No. 92/509 of July 16, 1990 which clarified that storms were excluded from the field of the natural disaster guarantee because they were an 'insurable risk', although could, if severe enough, be included under the field of 'events of abnormal intensity' and
- Act No. 92/665 of July 16, 1992 further excluding damage from ice, hail and the weight of snow. Catastrophic event categories that retained coverage were: flood, mudslide, earthquake, volcanic eruption, tsunami, earth movement and subsidence (Bidan, 2007).

Besides its "public mission" as a state-owned reinsurer providing unlimited cover against risks including natural catastrophes (except windstorms), and terrorism, the CCR also participates in the traditional insurance market, particularly in property, motor and life insurance. Its portfolio is focused primarily on France but is now spread throughout 20 countries in Europe, Asia, North America and Africa. The rates are set by decree and uniformly priced as a percentage of the premium charged for the primary property insurance *regardless of geographical location of the asset*. From 1983 to 1999 the premium rate was set at 5% of the primary rate eventually increasing to 12% in 1999 (Charpentier and Le Maux, 2010; Jametti and von Ungern-Sternberg, 2009).

Funding of the CCR
CCR resources consist of collected premiums, with shortfall in the event of catastrophe losses guaranteed by the government. The CCR had to cover 650 million francs in reinsurance losses in 1996 following three hurricanes in the Overseas Territories. By 1996 the CCR surplus was down to 300 million euro and so revisions were made. In 1999 the government had to inject a further 460 million euros to keep the entity afloat.

Despite the reforms, the CCR was practically bankrupt by the end of 1999, triggering the injection of government funds and more financial reform:
- premiums were increased to 12% of primary cover;
- deductibles were increased;
- commissions were abolished: the high commission-rate had been a contributing factor in the inability of the CCR to accumulate sufficient surplus to cover the losses of a major catastrophic event.[12]

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[12] According to an anonymous reviewer, following the drought of 2003, further changes were made, for example, deductibles now increase after multiple claims.

In 2000, premium rates were further increased by around 40% and reinsurance cover was limited to 50% (Jametti and von Ungern-Sternberg, 2006).

Interaction between the CCR and the Private Insurance Market
Insurers are not obliged to buy reinsurance from the CCR; they may obtain cover from the private market, but if they decide to reinsure with the entity there are two cover options available: proportional cover[13] which since 1996 was limited to between 40% and 90% of risk and then reduced to 50% in 2000; and stop-loss contracts[14] which were available to insurers holding proportional cover. Stop-loss contracts obliged the CCR to cover most of the cost of major catastrophic events. If the residual market mechanism did not have sufficient surplus to cover major events, the state guarantee would provide the shortfall and the tax payer would bear the brunt of the loss (Bidan, 2007).

Private insurers are required to collect the premiums for the CCR and administer policies. They are responsible for assessing the damage arising from catastrophic events, process claims and make payment within three months of the filing a claim.

Financial Position in 2012
Due to the fact that commissions were set at 24% when the CCR was established, and the entity reinsured mainly property in high-risk areas, the claims/premium ratio was initially 60% and consequently the CCR was not able to accumulate sufficient reserves to manage a catastrophic event. The storms of 1999 and the drought of 2003 effectively drove CCR insolvent (Jametti and von Ungern-Sternberg, 2009).

The CCR has still not accumulated a significant surplus and in the event of a catastrophic event in the near future, the government will again have to cover the shortfall. Jametti and von Ungern-Sternberg (2006) argue that "risk selection" is a major problem: private insurers are able to hand over "insurance of high-risk agents to the public part of the private-public partnership". Surpluses acquired by accepting only low-risk exposure are being accumulated by the private sector while the CCR has insufficient revenue to build up a surplus.

The ratings agency A.M. Best (August, 2011) rated CCR's financial strength rating at A++ (Superior) and issuer credit rating at "aa+" with a stable outlook. It viewed CCR's risk-adjusted capitalisation as very strong, supported by a conservative earnings retention policy and the backing of the Republic of France. In March 2012, however, the ratings agency expected CCR's 2011 profitability to be negatively affected by the 2011 Thailand floods, from which the CCR had suffered large losses causing it to withdraw from that market. More importantly though, the economic instability in Europe has led A.M. Best to review its 2011 ratings, due largely to the uncertainty of France's creditworthiness which could negatively affect the security of CCR's guarantee of backup. Although the ratings of 2011 were affirmed by the ratings agency, they were

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[13] With proportional insurance cover the reinsurer shares losses in the same proportion as it shares premium and policy take-up.
[14] Stop-loss contracts are policies designed to limit claim coverage (losses) to a specific amount. This type of coverage is to deal with catastrophic claims (specific stop-loss) or numerous claims (aggregate stop-loss). When total claims exceed the aggregate limit, the stop-loss reinsurance indemnifies the insurer.

qualified. Negative rating action could follow if the explicit support given to CCR by the French state or the creditworthiness of France were to change.

4.5.8   Flood Insurance in the United Kingdom

Background
While a residual market mechanism does not exist in the UK for natural hazards, the situation there in respect of flood cover is relevant to our discussion. For the past 50 years there have been agreements between the insurance industry to compensate for flood damage and the British Government to accept "requests" from the insurance industry to control floodplain development and increase funding for risk reduction measures. Despite this so-called "gentleman's agreement", the reality is that development on floodplains has become easier and spending on mitigation measures reduced (Department of Environment, Food and Rural affairs (DEFRA), 2012).

On July 11, 2008, the British government and the insurance industry signed a "Statement of Principles" -- a renewal of the formal Statement that commenced in 2000. This agreement obliges insurance companies to offer flood insurance as part of standard policies to all properties built before January 1, 2009, on condition that flood hazard is not more frequent than an Average Return Interval (ARI) of 75 years, unless these high-risk areas have risk reduction plans in place to be completed within 5 years.

By excluding the obligation to cover properties built post-January 2009, developers and purchasers of properties built after that date became responsible for ensuring materials and construction methods met insurable standards (Crichton, 2012; DEFRA, 2012). The agreement expires in June 2013.

In the summer of 2012, British insurers faced large flood damage losses with claims amounting to £2.5 billion. Caroline Spelman, the Secretary of State for Environment, Food and Rural Affairs released an optimistic ministerial statement on 11th July, 2012 stating that the government was working with the Association of British Insurers (ABI) on a number of proposals:

> *to formalise existing pricing arrangements and maintain the current cross-subsidy in place between policyholders by means of an internal industry levy. By reflecting existing arrangements the levy would avoid increasing costs for those not at risk whilst maintaining insurance affordability to households in flood risk areas. . . Meanwhile, this Government is continuing to fulfil its role in reducing flood risk by spending more than £2.17 billion on flood and coastal erosion risk management in England over the current four year spending period… The recently published National Planning Policy Framework fulfils the Government's commitment to avoid unnecessary building in floodplains and this outcome has been welcomed by the ABI and others….*
> (http://www.parliament.uk/documents/commons-vote-office/July_2012/11-07-12/5.DEFRA-Update-on-managing-the-impact-of-flooding.pdf.)

At the time of writing, discussions between the Government and insurers on the continuation of the agreement have stalled.

Pricing and Cover
In 2007 the legal definition of "flood" was established and insurance companies had the choice of excluding flood cover or adding excesses (deductibles) to homeowner

policies (Crichton, 2012). Importantly, the Government provides no compensation for flood damage (Botzen, 2011).

The present "Statement of Principles" agreement encompasses risk-based pricing of excesses and premiums but insurers have tended not to apply this principle and instead spread risk geographically for simplicity and commercial reasons. This means that policyholders in low risk areas have been subsidizing the costs for policyholders in high risk areas. Resulting adverse selection recently caused insurers who were being undercut in low-risk areas to move towards risk-based pricing and the reduction of cross-subsidies (DEFRA, 2012)[15]. Cover is optional although lenders require coverage for mortgage eligibility. There is low uptake by low-income households.

Government Initiatives
DEFRA states on its website that it is committed to ensuring that flood insurance remains widely available in England after expiration of the agreement, and that the best way to ensure this would be for Government, communities, individuals and businesses to reduce the levels of local flood risk. Property owners should flood-proof their homes to reduce the probability and extent of damage. Flood proofing should result in better terms for flood policies.

At the Flood Summit in September 2010, three working groups were set up to consider options for future management of flood risks and ensuring that flood insurance remain widely available when the agreement expires in 2013.
- The first group was to identify options for managing the financial risks of flooding after 2012.
- The second group was to find ways to ensure that flood risk information is transparent and available to all.
- The third group looked at how resistance and resilience measures could reduce risk, reduction of barriers to mitigation and how best to promote and communicate such measures.

Since receiving progress reports from the working parties in May and July 2011, government has continued to develop and analyse the options, in close association with the insurance industry. Following the statement from insurers that they would not renew the agreement when it expires in 2013, a proposal from the Association of British Insurers (ABI) of a restructuring of private/public participation in flood cover is currently before government (Cullen (ABI), 2012 pers. com.). The dialogue continues.

Mitigation Issues
The British Government has concluded that rather than subsidizing premiums for people in high flood-risk areas, funds would be better directed at reducing risk (DEFRA, 2012). DEFRA found measures, such as installing temporary flood guards and air brick covers, could reduce damage by about 50%. Additional permanent measures can further reduce potential flood damage but at greater cost. The use of flood resilient plaster, flooring and materials used in kitchens are all very effective in reducing damage in buildings that are frequently inundated.

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[15] This trend towards risk-based premiums is also occurring in Australia.

Resistance measures were found to be more effective with low-level flooding and resilience measures more effective with higher water levels because they reduce restoration, clean-up and alternative accommodation costs and they are also more suitable for blocking high flood waters (Dawson et al., 2011; Botzen, 2011).

Climate Change Issues
The Association of British Insurers (ABI) commissioned research to look at the implications of climate change for the UK (ABI, 2009). Climate and risk models were used to assess the effect of changes of 2, 4 and 6 C in mean temperature on inland flooding and windstorms in the UK, and estimate how these changes would impact on insured losses, insurance pricing and capital requirements.

Results suggest that climate change will bring about more precipitation and increased inland flooding in all areas of the UK. As a consequence, insurance premiums would need to rise between 16% and 47% depending on the temperature projection scenario. The minimum additional capital required to ensure cover availability was between £1 billion and £5.6 billion. No clear increase in frequency or severity of windstorms is anticipated, but a slight change in cyclone tracks could be expected which could increase average annual windstorm losses by 25% (Botzen, 2011).

4.5.9 The Netherlands

Background
The approach to catastrophe management in the Netherlands where flood risk has been considered to be uninsurable is in stark contrast to the systems discussed previously in this report. The Netherlands is located on the Rhine-Meuse-Scheldt delta and 50% of the land lies below sea-level. Low-lying and particularly vulnerable areas are located in the western half of the country (with approximately 9 million inhabitants), in areas where agricultural land has subsided, in reclaimed lake areas (known as polders) and areas along the banks of the Rhine and Meuse (Botzen, 2011).

The main challenge now is not the long-term development of the coastal defences, but rather the long-term protection of the densely populated areas in the lower reaches of the Rhine, where sea level rise will interact with river discharges (PBL Netherlands Environments Assessment Agency, 2011, http://www.pbl.nl/en/). Under a warmer climate, the Agency anticipated that the country's vulnerability to both coastal flooding from the North Sea and riverine flooding from the Rhine and Meuse will only be exacerbated by sea-level rise and the potential for increased peak flows in the Rhine (Botzen, 2011).

The inhabitants have not had easy access to private homeowner insurance for natural disasters since the major flooding event in 1953[16] and there is no public insurance program. (Some commercial flood cover is available from overseas companies such as

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[16] During the night of 31 January 1953, a flood disaster hit the South-west of the Netherlands. About 1850 people and tens of thousands of animals lost their lives. Around 100,000 people had to be evacuated, 4500 buildings were destroyed and many more were damaged. Almost 200,000 hectares of land were flooded. It was nine months later before the last hole in the dike was closed. This same storm caused significant damage in the UK and led to the Thames barrier being constructed.

Lloyds). Responsibility for both compensation for flood damage and mitigation lie in the hands of the Dutch government. There is no capital base and no definition of eligibility or extent of relief. Thus the inhabitants must depend on the largesse of the government of the day for compensation, and there is increasing reluctance by governments to provide such compensation for budgetary reasons (Botzen, 2011).

Mitigation
Dykes have been a feature of the Netherlands' attempts to protect the low-lying land at risk from riverine flooding, polders and land reclaimed from the North Sea for over 2000 years. When windmills with rotatable heads were invented, they were used to pump water out of reclaimed land surrounded by dykes (Gerritsen, 2005). The land above sea level consists roughly of two parts running along the coast with moderately higher ground to the east and north. The lowest point, located between Rotterdam, Gouda and The Hague is about 6.5m below sea level. Canals and pumps are needed to drain seepage or precipitation out of the low lying areas and discharge the effluent into the sea (Gerritsen, 2005).

The 1953 flood disaster was caused by surge from a major storm across northwestern Europe that tracked close to the Netherlands. The surge coincided with a spring tide causing record high water levels. During the night of January 31 to February 1, 1953, overtopping waves caused the dykes to begin collapsing. Despite radio bulletins warning of the danger of the potential high water levels, the extent of flooding came as a surprise to much of the population. Peak height occurred during the night, breaching 150 sea dykes and more inner dykes. Once the dykes were breached there was nothing to prevent the spread of water through the low lying areas they had been protecting (Gerritsen, 2005).

In response to the flooding of 1953, the Delta Works was built. The project provided the construction of 53 dyke-ring areas, each a closed system consisting of dams, dykes, sluices and storm surge barriers that took until 1997 to complete. The system needs to be updated continually to adapt to sea-level rise and increased precipitation. Each dyke-ring has its own separate administration under the Water Embankment Act of 1995, which guarantees a specified level of protection. Protection standards of individual dyke-rings are higher near the coast because coastal surge is more damaging and difficult to predict and also due to population density and economic activity in those areas. According to Aerts et al. (2008), with rising sea levels, the probability that water could overtop protection near Amsterdam and Rotterdam could increase with a factor of 2 per 25 cm sea level rise.

Most mitigation measures to date have focused on reinforcement and heightening of dykes. The extent of sea-level rise, however, and the prerequisite adjustments that must be made to flood-protection infrastructure in the Netherlands remain uncertain, and other additional mitigation measures have been considered. A scheme "Attention for Safety" would require the elevation of new homes to several metres above sea level (Aerts et al., 2008). An extensive online survey of 473 households found that 52% of respondents would be prepared to invest 10,000 euro in elevating a new house to eliminate flooding risk (Botzen, 2011).

Role of private insurance

As the cost of disaster relief is rising, the previous governing coalition was becoming increasingly reluctant to continue being *the insurer of first and last resort*. It remains to be seen which direction a future elected government will take with regard to flood risk and compensation.

Legislation requires that the Delta Works provide protection to ARI 10,000 along the coast and ARI 1,250 along the river banks, but weaknesses have been found in some dykes offering protection from river overflows. For example, In January 2012 inhabitants and animals were evacuated when a dyke in the province of Groningen began leaking and a breach was threatened.

With climate change increasing vulnerability and exposure dependent on adaptive mitigation measures, especially in the updating and strengthening of the Delta Works, a private insurance market would likely have to apply high basic deductibles, offer limited cover and purchase costly reinsurance to remain sustainable. Under these conditions, government and the public may not consider the cost of taking out insurance cover to be worthwhile.

4.6 Influence of Residual Market Mechanisms in effecting Mitigation and Risk Reducing Behaviours

Here we draw from the examples of the schemes reviewed in the previous section that have been at least partially successful in driving behavioural change or building practices to reduce risk. We do not include the Florida Windstorm scheme (Citizens), the Spanish and French arrangements or the Californian earthquake Authority because they do not appear to provide incentives or encouragement for mitigation. We begin with one that was not reviewed but where one of the authors (G.R. Walker) was personally involved.

4.6.1 Cyclone and flood insurance in Fiji.

In respect of cyclone insurance, buildings, including residential houses, have to be certified as either meeting the code (newer construction) or to have been upgraded to the standards in a document called *Our War on* Cyclones (FBSC, 1995) following Cyclones Eric and Nigel. The requirement has had a big influence on improving the resilience of housing, particularly older housing similar in construction to most pre-code housing in northern Australia.

About the same time, a condition was inserted in flood insurance policies that claims for movable items would only be accepted if the depth of flooding exceeded a level of about 600mm, i.e. greater than bench and table height. This has had a significant impact on claims as previously it had become common practice to ensure all older stock in shops and older items in homes was deliberately placed on the floor to maximise their chance of being replaced.

4.6.2 National Flood Insurance Plan

Flood insurance in the US is only available to property owners if the local authority in which their property is located enforces FEMA flood management guidelines. While the take up of flood insurance has been limited, almost all local authorities have adopted the FEMA guidelines because residents didn't want their local authority on a black list. Consequently it has had a significant impact on flood management in the US.

The big problem with the scheme is that while newer properties can only be insured if built and located according to these guidelines, property built before the scheme was adopted is exempted from this requirement. Since these older homes comprise a large proportion of insured property, they give rise to most of the flood losses. Premiums for newer construction are risk-rated, albeit coarsely, whilst those for older structures are not and are consequently being subsidised by the scheme. The result is that the scheme is deeply in debt.

The NFIP is a scheme that can be regarded as not very successful in terms of insurance, but very successful in terms of acting as an incentive for ensuring national acceptance of the FEMA flood management guidelines – a rare phenomenon in the US where local authorities still control most forms of building standards. It is something that has yet to be achieved in Australia where local authorities still play a major role in the specification of flood management standards.

4.6.3   The Texas Wind Storm Insurance scheme

To be eligible for flood cover, the Texas scheme requires structures built in coastal regions since the scheme was inaugurated to meet specified standards. Conformity has become almost universal in these coastal regions because the first question prospective owners are likely to ask when considering the purchase of a building is whether it meets these standards, even though this may not be required by local authorities. Again older construction is exempted.

This scheme has been in trouble after its reserves were totally exhausted by Hurricane Ike. The basic problem is a political process which keeps the premiums of those at high risk much lower than they should be. Losses in excess of reserves are transferred to the rest of the citizens in the State through assessments on insurers. The scheme is successful both in terms of mitigation and provision of insurance, but from an operating point of view it is only sustainable by a large amount of subsidisation of the politically strong coastal community by those in more inland areas not covered by the scheme.

4.6.4   The British flood insurance contract

The British government and insurance industry came to an agreement to provide universal flood insurance providing the government put in place an acceptable level of flood management nationwide. Crichton (2012) argues that apart from Scotland, the government has in many areas failed to meet the expectations of the insurance industry in meeting their part of the agreement. The possibility of the insurance industry not renewing the agreement when it expires in 2013 has given rise to much discussion in the UK about what this will mean, with warnings of 260,000 houses likely to be denied flood cover from next year (Nick Starling, Association of British Insurers, pers. com.). Association of British Insurers has proposed a new framework to replace the "Statement of Principles". The "Statement of Principles" scheme has been very successful from a consumer point of view, has resulted in some improvement in mitigation, particularly in Scotland, but has proved unsatisfactory from an insurance industry viewpoint.

4.6.5 EQC

While the EQC has no direct responsibility for mitigation it has played a major role in supporting research and development related to earthquake mitigation and promoting the continuing improvement of building codes and planning regulations in relation to mitigation of earthquake losses. However because premiums have not been risk-rated and do not distinguish between high- and low-risk construction, it provides no incentive at all for upgrading older houses. In fact because of replacement insurance policies it can be shown that their approach produces a disincentive since any upgrading to an older structure reduces the chance of an owner getting a new house for the old one if it is severely damaged in an earthquake (Walker and Musulin, 2010).

4.7 Discussion

There are no residual market mechanisms currently operating in the Australian insurance market in respect of natural catastrophe risks. It has been considered, however, in the past (Walker, 2011) and more recently in relation to riverine flooding following the 2011 Queensland and Victorian floods (van den Honert and McAneney, 2011). To determine whether a system that included a government-run pool could be successfully developed to improve resilience to the future impacts of catastrophe losses and by extension to their possible amplification by future global climate change, we have reviewed the provision of catastrophe insurance in a number of countries. A key conceptual point is that while governments can defer paying for today's losses into the future, an insurer cannot and must have capital or reinsurance in place before losses occur.

The review is not exhaustive, but, nonetheless, samples from the spectrum of possible arrangements. It examines the challenges that beset them in dealing with the rising cost of natural disasters and, in the case of the weather-dependent risks, the likelihood that global climate change may at some future point alter the risk profile. Each of the residual market mechanisms examined reflects the particular history of losses and cultures of the countries or States involved. The residual market mechanisms of California and Florida were developed to deal with the threat of earthquakes and hurricanes. Some of the other arrangements, e.g. EQC in NZ and CCS in Spain, deal with a wider range of hazards, although the hazard profile differs widely between countries.

In Spain most hazards are covered by a government fund that is administered in effect as social welfare; in France insurance companies are required to cover most hazards as part of standard policies, with the government offering subsidized reinsurance as an alternative to the commercial reinsurance market. In the UK, there was an understanding between government and private insurers that insurers would cover most hazards in return for a government promise to address flood risks in particular. At the other extreme is the Netherlands, which faces flooding as an existential threat, and where the focus has been on national flood defences. No private sector insurance exists in this country to cover the threat.

An ongoing contentious issue in the US has been the degree of political influence exerted on the pricing structure of residual market mechanisms. In an attempt to keep prices affordable and encourage take-up rates, there has been a tendency to keep premiums too low and to have policyholders in low- and high-risk areas charged similar rates that do not reflect their actual risk. Because of the lack of financial incentives for mitigation, this practice encourages development in high-risk areas. Calls for reform in

the US may bring about some positive changes in the residual market mechanisms, but there is debate as to the place a state-run entity should have in the insurance market.

Government pools have certain advantages over the private sector in being able to spread losses across time as deficits caused by catastrophic losses can be passed on to future generations. Governments are not intended to make a profit, and pricing need not reflect the cost of capital[17]. With financial backup or guarantees from the state, they can fall back on resources not available to the private sector. Usually they are not at risk of insolvency as in the case of EQC, which was bailed out by the New Zealand Government after the Christchurch earthquakes.

The ability to raise taxes and issue bonds to pay for losses post-event is something generally only governments can do. However, as Hartwig (2009) points out, their capacity to do so may be constrained. The Global Financial Crisis (GFC) that began in July 2007 left the residual market mechanisms vulnerable to the possibility that they could fail to meet claims for damages from major catastrophic events. The private market was also impacted with high underwriting losses, plunging asset values and investment earnings. No catastrophe insurers or reinsurers actually collapsed as a result of the last GFC but they need to add the risk of disruption in global capital markets to their future financial resources and pricing policies.

Funding of US pools has traditionally been through assessments on insurers and tax offsets for "voluntary" writings in high risk areas. This works acceptably well unless losses must be spread over long time periods through bonds, as is done in Florida. The standard assessment mechanism, which freezes deficit proportion at the time of loss based on market share, breaks down if applied to a bond repayment over 20 years, when the insurer may have left the market or have a very different revenue stream. Also, US accounting rules force insurers to book the full future value of the liability at the time of loss even if the liability is funded by bonds that will not require repayment for decades. These reasons are behind important changes to the Florida (and Louisiana) pool funding mechanisms to issue "emergency assessments" directly on policyholders to pay off bonds; this operates like a Goods and Services tax on insurance premiums.

The role of federal government in the US can be influential in encouraging the uptake of catastrophe insurance. US Federal mortgage requirements, for example, mandate flood and hurricane insurance, but curiously do not require earthquake cover. This explains the almost universal take-up rate on hurricane insurance and the very low take-up rate of the CEA in California, although it does not explain the far from universal take-up of flood insurance.

We conclude this section with a list of the salient points to emerge from our examination of examples of government involvement in the insurance market and the degree to which this has been successful in driving adaptation to extreme weather risks:

1. It seems difficult to combine compulsory insurance systems with successful incentives for mitigation. If the insurance is to be compulsory then the mitigation 'incentives' need to be compulsory as well.

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[17] See Appendix 1, which deals with the cost of capital.

2. Although risk-rated premiums provide an incentive for mitigation, we are not aware of any examples where these have yet proved successful in encouraging risk reduction on a significant scale. Nevertheless they are essential for sustainable commercial insurance operations and send a strong signal to land-use planners with regard to further development of floodplains, etc. Technology to risk-rate individual properties for location-specific natural perils like flood, bushfire and storm surge is increasing in its availability and capability.

3. Risk reduction seems most successful where there is an external pressure exerted on individuals resulting from the program as in the Texas wind scheme, or on the local community as for flooding in the US through NFIP.

4. External pressure for hazard mitigation doesn't appear to work so well at a national level as demonstrated in the UK where insurers felt that the long term prospects for adequate flood defences did not look promising and feared that the blame for non-payment of losses would fall on them.[18] However, mitigation against flood in the form of dams or levees may actually encourage further development in the so-called protected zone and when these levees eventually fail or overtop in more extreme floods than designed for in their construction, losses will be amplified.

5. As demonstrated in Texas and Fiji insurance can provide incentives for mitigation where there is strong demand for insurance and it is not compulsory. However in respect of natural hazards, incentives only seem to be provided in storm and tempest cover. Wind (and earthquake) mitigation is much more a responsibility of property owners, and risk-based premiums would probably be more appropriate in conjunction with guidelines on what was required in terms of retrofitting to avoid high premiums. In Australia, such guidelines already exist in relation to upgrading typical older timber framed houses in Queensland. There could be some incentives such as government assistance and/or tax concessions on money spent on upgrading if undertaken within a prescribed time frame.

6. In relation to flood mitigation, retrofitting individual homes is generally expensive, and so it is the local authorities, who hold the key. Consequently the compulsion and penalties would need to be applied at this level. Since most of the areas at risk of flooding are well known, there is little excuse for the continued development of floodplains in a manner that is not flood resilient.

With political will and well-informed debate it may be possible to get the balance right and have the voluntary and public providers working together as drivers in adaptation to the uncertain effects that climate change will have on exposure and sustainability. However our review has revealed no silver bullet. Most residual market mechanisms have not to this point applied risk-adjusted premiums and in most cases government

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[18] According to an anonymous reviewer, a second (unspoken) factor was that the old guard insurers had become burdened with a heavily cross-subsidized portfolio, while newer insurers were selecting low-risk properties, and the trend was accelerating with access to more accurate geo-spatial analyses. Thus it suited the traditional insurers to see the break-up of the agreement anyway, particularly if they could blame the government for it.

involvement has proved unhelpful in reducing the societal risk. If premiums are to be truly risk-rated then the community will have to accept that this will logically result in reductions in house prices in high risk areas to reflect the revised value of increased premiums.

4.8 Implications for Climate Change Adaptation

Based upon our examination of the roles of government and the private sector in dealing with extant catastrophic natural hazard risks, it appears that encouraging adaptation to climate change will likely entail a high degree of compulsion. As we see it, this is not a role for the insurance sector whose main responsibility is to its shareholders and its main game the rigorous assessment and transfer of risk, as it is currently assessed. This commercial imperative nonetheless could have socially desirable outcomes if it were to encourage changes by government and other actors to invest in mitigation infrastructure, better building codes and risk informed land-use planning practices.

Risk-rated premiums would send a transparent risk signal to all parties, and, if this were successful in changing behaviour, over time the population at risk to natural disasters should decrease, or at least not continue to rise in concert with increasing general population and wealth. This should in turn entail a contemporaneous reduction to exposure to any climate change enhancement of extreme weather. Unfortunately our review has revealed few instances of this happening yet, even where the risk is well understood. However the tools to achieve this are increasingly available and accessible by insurers.

Other factors stand to confound the socially desirable scenario of risk reduction outlined above. One of these is human behaviour with experience with voluntary flood and earthquake insurance in the US showing that consumers are reluctant to pay for insurance to cover natural hazards with a low probability of occurrence (Pasterick, 1998). Similarly, surveys of victims of the 2011 floods in Australia reveal little appetite to spend relief or insurance monies to reduce risks to their homes from future events (Bird et al., 2012).

Lastly and on a more positive note, insurance at its core is about the financial management of *uncertainty* and the tools it employs to assess this uncertainty may be more generally useful in reframing the debate over climate change. Acknowledging the uncertainty in the impacts of climate change on extreme weather as indicated above may help move us beyond the sterile debate that in Australia is currently anchored in the mutually exclusive 'certainty' of the sceptics on the one hand, and the proponents for dramatic societal action on the other. Both camps are equally intransigent and as one commentator put it:

> *each side argues that if you could only see the science from my perspective, then the way forward would be clear* (Pielke Jr., pers. com.)*.*

To the degree that uncertainty has a positive price - the more uncertain the outcome, the higher the premium required to replace this outcome with a certain one - then some investment in adaption and mitigation can be seen as prudent hedge against the worst outcomes.

5. SECURITISING INSURED NATURAL HAZARD RISKS – A HYPOTHETICAL SYDNEY FLOOD CASTROPHE BOND CASE STUDY

5.1 Abstract

The market for catastrophic event risk witnessed an important change during the late 1990's with the issue of the first successful Catastrophe (CAT) Bonds. This type of insurance-linked security is used to transfer natural hazard risks to the capital markets -- a process called securitisation. CAT bonds complement the traditional reinsurance market by broadening capacity and are attractive to investors because they are largely uncorrelated with the returns on other stocks and bonds, as well as offering superior returns.

Australia is afflicted with a wide number of hazard types with losses due to bushfire, earthquake, flood, storm and tropical cyclone each featuring in the top 10 normalised insured disaster losses since 1967. Here we examine a hypothetical Sydney flood CAT bond for flood risk to residential buildings and contents in the Hawkesbury River basin, one of the more at-risk floodplains in Australia. The flood risk is modelled under different building floor height scenarios using Risk Frontiers' FloodAUS loss model, a probabilistic loss model that estimates losses for insurer portfolios by generating a catalogue of plausible event losses and using these to derive insurance-relevant statistics.

The cost of transferring flood risk in the Hawkesbury River basin using a CAT Bond is estimated to be around 15 to 75% higher than that of traditional reinsurance. This range is very much an upper bound estimate. However, reinsurance is increasingly not rated as highly as CAT Bonds (one of the few sources of triple-A rated security) so whether this difference is too much to pay for guaranteed security is a decision for individual insurers and/or governments.

A government could purchase a CAT Bond to cover a specific concentration of risk in order to have assurance that it would not have to draw upon funds ex-post from the current account. This would be a possible means to cover legacy risks that prove unattractive to insurers if the risk is assessed as too high. This legacy problem has been amplified by successive governments allowing uninhibited development in flood plains or within bushfire-prone bushlands in Australia and in flood and cyclone-prone areas elsewhere.

Looking to the future and absent government intervention, large concentrations of exposure in areas of very high-risk will continue to emerge and this risk may in turn be amplified due to adverse anthropogenic climate change. CAT Bonds can help manage these risk concentrations. However, while these instruments are useful for transferring risk they are not an alternative to reducing vulnerability. Measures such as risk-informed land-use development and hazard resilient construction could dramatically reduce the risk and thus the need to transfer this risk. While our case study examined flood risk, the methodology is easily transferable to other perils such as bushfires.

5.2   Introduction

Catastrophe (CAT) Bonds are a type of insurance-linked security that transfers natural hazard risks to the capital markets. This report examines these bonds and presents a hypothetical Australian case study. It is the final of three studies undertaken for an NCCARF-funded project S11-17 entitled *Assessing the potential for and limits to insurance and market based mechanisms for encouraging climate change adaptation*.

Section 3 of this report showed that the economic cost of natural disasters due to extreme weather – tropical cyclones, floods, bushfires and storms – is rising mainly due to growing concentrations of population and wealth in disaster-prone regions. More large concentrations of exposure in areas of very high-risk are expected to emerge due to increasing development. CAT bonds can help manage these risk concentrations. They complement the traditional reinsurance market by broadening capacity for these 'peak' perils.

The top 10 normalised Australian insured losses between 1 July 1966 and 1 December 2012 are given in Table 4. The normalisation adjusts historic losses to current societal conditions and building practices in the case of tropical cyclones. The 1999 Sydney hailstorm ranks highest with a normalised insured loss of approximately AUD$4.3 billion. Five different hazard types feature in the top 10 normalised insurance natural disaster losses, the most recent of these being the 2010/11 Queensland floods.

To date, Florida hurricanes, California earthquakes, European windstorms and Japanese earthquakes have dominated CAT Bond issuances. The *Australis* CAT Bond series is the only one to have dealt with Australian risks, namely tropical cyclones and earthquakes. In what follows we explore how a CAT Bond might be structured around a flood in the Hawkesbury River basin. The methodology can easily be extended to other peak concentrations of risk such as Brisbane.

Our report is constructed as follows: we begin with an introduction to CAT Bonds including the benefits they offer investors. We then describe the National Flood Information Database (NFID), which comprises a database of flood hazard information, and validate it by comparing the extent of the January 2011 flooding and the January 1974 flooding in Brisbane. The following sections introduce Risk Frontiers' probabilistic flood loss model, detail the national residential portfolio employed in our analysis and provide an overview of flooding in the Hawkesbury River basin. Sub-section 4 focuses on the attributes of the hypothetical flood bond and conclusions are drawn in Sub-section 5.

Table 4: Ten highest ranked normalised insured losses (AUD$ million) (source: Crompton (2011) updated and current as at 3 Dec 2012).

Rank	Event	Year	Location	State	Loss (AUD$ million)	Normalised loss (2011) (AUD$ million)
1	Hailstorm	1999	Sydney	NSW	1700	4296
2	Tropical Cyclone Tracy	1974	Darwin	NT	200	4090
3	Earthquake	1989	Newcastle	NSW	862	3240
4	Flood[a]	1974	Brisbane	QLD	68	2645
5	Flood	2010/11	Multiple	QLD	2388	2516
6	Hailstorm	1985	Brisbane	QLD	180	2063
7	Ash Wednesday Bushfires[b]	1983	Multiple	VIC/SA	176	1796
8	Severe Storm	2007	Multiple	NSW	1480	1742
9	Tropical Cyclone Madge	1973	Multiple	QLD/NT/WA	30	1492
10	Tropical Cyclone Yasi	2011	Multiple	QLD	1412	1469

[a]The 1974 Brisbane flood resulted from the degeneration of Tropical Cyclone Wanda.
[b]The two separate loss entries in the Disaster List for this event have been combined into a single loss.

5.3   Catastrophe Bonds

5.3.1   Securitisation of Insurance Risk: Introduction to Catastrophe Bonds

An active insurance securitisation market developed during the late 1990's in response to capacity constraints in the traditional reinsurance markets. Large losses from US catastrophes in the late 1980's and early 1990's (Hurricanes Hugo and Andrew, and the Northridge earthquake) put strains on the reinsurance markets. It was realised that losses from similar events had the potential to be far more severe: for example, a three times greater loss could have occurred had Hurricane Andrew made landfall only 30 kilometres further north in the centre of Miami. The case for Insurance-Linked Securities (ILS) strengthened after the 2005 hurricane season in the US that included Hurricane Katrina.

Like other types of bonds, CAT Bonds involve periodic interest (called coupon) payments and return of principal at maturity. A CAT Bond has the unique feature that the principal and coupon payments are at risk, with full repayment conditional on the non-occurrence of a specified natural catastrophe, the performance of an insurance portfolio or the value of an index of catastrophe risks (Swiss Re 2011). CAT Bonds function like multi-year reinsurance contracts and they relate to the CAT Excess-Of-Loss (XOL) segment of the reinsurance market.

There are two key areas where insurance risk can be securitised: the first is for insurers with very large exposures in catastrophe-prone areas, and the second as a form of retrocessional capacity. (Retrocession refers to reinsurers insuring another reinsurer in order to spread the ceded risk around.) One of the main reasons for reinsurers accessing the capital markets is that reinsurers tend to charge considerably more for retrocessional coverage. Other less significant areas to date include corporate- and government-sponsored transactions.

Generally, CAT Bonds target higher reinsurance layers, which mean that investors have a low probability of loss. For example, a layer may attach at the 1% Annual Exceedance Probability (AEP) (100-year Average Recurrence Interval (ARI)) and exhaust at the 0.4% AEP (ARI of 250 years). As layers become higher and probabilities of loss lower, traditional risk transfer ultimately becomes less economical and lack of capacity and counterparty credit risk of more of a concern.

The typical structure of a CAT Bond is illustrated in Figure 4. The special purpose vehicle (SPV), effectively a dedicated company, is created and performs two functions. The first is to underwrite reinsurance in exchange for the premium paid by the cedent (sponsor) to the SPV. The second function is to issue securities to investors, thereby raising the required capital to fully collateralise the reinsurance underwritten. The premium and investment income on the trust provide the funding for the bond coupon the investors receive.

As has already been stated, investors receive back their principal at maturity if the CAT Bond is not triggered by a specified event during the risk period. Should it be triggered, the investor will receive only that portion of the principal and coupon that remains after paying the cedent's event losses under the agreement.
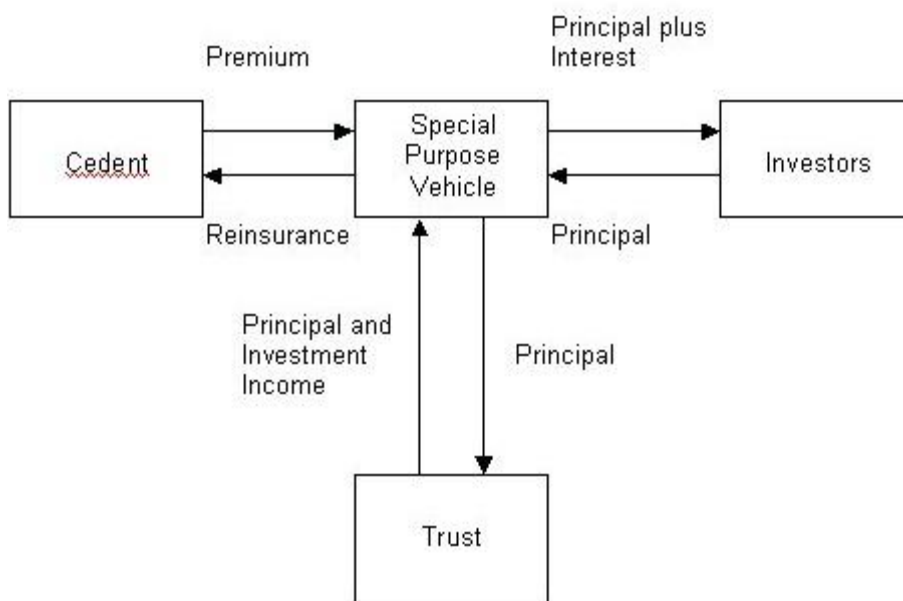

Figure 4: Structure of a CAT Bond (source: Canabarro et al. (1998)).

When a CAT Bond is structured, a payout trigger needs to be selected. This defines the losses in the contract between the cedent and the SPV. The trend in more recent issues is towards the use of indemnity triggers and away from industry index triggers (Figure 5).

In an indemnity-based contract the trigger is based on the actual loss experience of the cedent's own book of business. This closely resembles a traditional reinsurance program. Loss payments could alternatively be based on an index of industry loss experience e.g. derived from a credited reporting service (assuming one exists) such as the Property Claims Service (PCS) in the US.
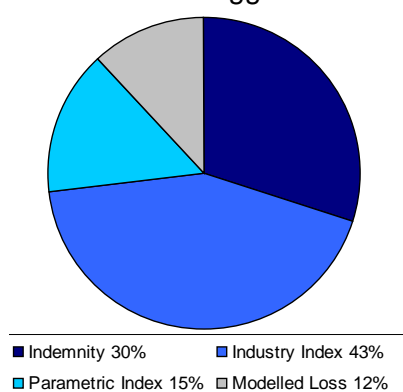
Catastrophe models can also be used to create triggers. A so-called 'modelled loss' is calculated by running a scenario event's physical parameters against the ceding company's portfolio of exposures. The transaction loss payout then settles on the modelling firm's estimate rather than actual losses.

Physical parameters of a natural hazard, such as the magnitude and location of an earthquake can also be used to trigger loss payouts. These pure *parametric* triggers can be adapted to create *parametric index* triggers by using a greater number of locations with different weights applied to each reflecting the ceding company's portfolio in the area. This refinement reduces the *basis* risk – the mismatch between losses to the reinsured portfolio and the recovery provided by the CAT Bond – associated with this type of trigger.

There are trade-offs between the various trigger types. For example, parametric triggers are the most transparent to investors while an indemnity-based contract is not subject to basis risk.

Different trigger types also require varying degrees of disclosure of the cedent's portfolio, give rise to more rapid payouts, and raise fewer investor concerns about moral hazard (that ceding risk negatively alters the incentives of the sponsor) and adverse selection (the fear that the sponsor is ceding precisely those risks it deems most problematic) (Swiss Re, 2011).
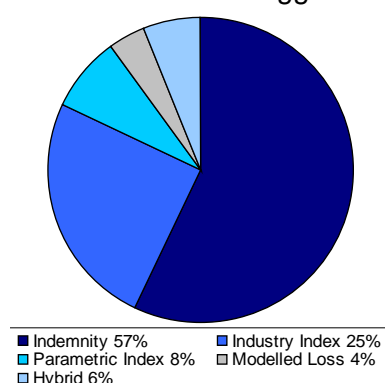
2007 CAT bond triggers

2012 CAT bond triggers

■ Indemnity 30%   ■ Industry Index 43%
■ Parametric Index 15%   □ Modelled Loss 12%

■ Indemnity 57%   ■ Industry Index 25%
■ Parametric Index 8%   □ Modelled Loss 4%
□ Hybrid 6%

Figure 5: 2007 and 2012 first half CAT Bond triggers (source: Swiss Re (2012b)).

CAT Bonds overcome a couple of drawbacks associated with the traditional approach used to transfer catastrophe risk. When issuing a CAT Bond, the cedent bears no credit risk. The funds in the safe account are specifically held for the purpose of paying cedent event losses should a catastrophe occur. They provide full collateral for the risk limits offered through the transaction. The transaction should also be memory-less: because the CAT Bond is purchased in the capital markets, the transaction should contain no judgements about past events.

CAT Bonds are attractive to investors because they are largely uncorrelated with the returns on other stocks and bonds and offer superior returns.

5.3.2   Securitisation of Insurance Risk: Investors Perspective

The investor base has widened from insurance and reinsurance companies to include: commercial banks, mutual funds, institutional money managers, and dedicated CAT Bond funds. To address the question of investor interest, the diversification opportunities that CAT Bonds present for investors need to be considered.

It will be helpful to begin with some basic definitions and review some finance theory. Firstly, what is risk? In a financial sense, we mean that outcomes may vary from what was expected. More formally we usually identify risk as the standard deviation of the distribution of returns on an investment.

Risk is further broken down into market and unique components. The holder of a diversified portfolio of shares, in different companies and in different parts of the economy, is only exposed to the *market* or *systematic* risk as it is sometimes called. Market risk stems from the fact that there are economy-wide factors that impact upon all businesses. This is why share prices have a tendency to move together. The risk that has been eliminated by diversification is the unique or non-systematic risk peculiar to a particular company and perhaps its immediate competitors. Technical risks facing an R&D company or exploration risk in some parts of the oil and gas sector are examples of unique risks.

Finance theory also tells us that the risk of an individual asset should be judged on the basis of its contribution to the overall risk of the portfolio. Depending on its degree of correlation with the other assets in the portfolio, the contribution of an asset can increase or decrease overall risk. Adding a risk-free security such as a government bond to a portfolio of otherwise risky stocks, will result in a linear reduction in portfolio risk (Brealey and Myers, 1996).

Why is all this relevant? Well, so far at least, no natural catastrophe has had worldwide impacts on the financial markets. The corollary is also true – there is no way that a hiccup in the financial markets can precipitate an earthquake or tropical cyclone for example. And thus to a good first approximation, we can say that the returns from CAT Bonds are uncorrelated with those from other financial assets - shares and bonds. In other words CAT Bonds present little systematic risk. As a consequence, investing a small proportion of a diversified portfolio in CAT Bonds that have low probability of loss will reduce portfolio risk by almost as much as the purchase of a risk-free security.

In other words, in order to improve the risk-return profile of a portfolio, a CAT Bond need only earn an expected return slightly above the risk-free rate. In fact, CAT Bonds have previously offered investors very attractive returns and even as the market matures (with little or no premium for 'newness'), still offer opportunities to earn high returns.

The concept of diversification can be demonstrated in a variety of ways. Belonsky et al. (1999) consider a hypothetical CAT Bond that pays an agreed yield if no catastrophe occurs but in the event of a catastrophe, whose probability can be estimated, suffers a total loss of principal. The variance of returns to the security increases with the probability of catastrophe. The extent to which holding the security reduces overall portfolio risk is therefore determined by this probability. Four securities are compared: a risk-free security (such as a Treasury Bill) and three CAT Bonds with probabilities of total loss of principal of 0.5%, 1.0% and, 2.0%.

Belonsky et al. (1999) looked at how effectively each security reduced risk when added to a portfolio of risky assets. As expected, and for all allocations of 10% or less, each of the three CAT Bonds provided nearly as much portfolio risk reduction as did the risk-free asset. With 5% of a portfolio allocated to a CAT Bond securitising a catastrophe risk whose probability of occurrence was 1%, the portfolio risk was reduced by 97.4% compared with 100% for the risk-free security.

Belonsky et al. (1999) also considered what the required spread above the risk-free rate would need to be in order for an investor to be indifferent between selecting a risk-free security and a CAT Bond. For the same hypothetical bond discussed above, a 113 basis point (bp) spread (1.13%) would provide sufficient incentive for investors to allocate 5% of their portfolios to the CAT Bond. This comprises 100 basis points to compensate the investor for the 1% expected loss and 13 basis points to compensate for the slightly smaller amount of risk reduction achieved. Previous issuances with a similar risk of loss have paid annual yields well above this figure.

The risk of an investor losing the entire principal of an aggregated CAT Bond holding becomes even smaller if the investor can diversify across several CAT Bonds with independent risks. Currently, the outstanding bonds cover a range of independent catastrophe risks and some offer multi-peril coverage.

5.4.   Flood Modelling

5.4.1   The National Flood Information Database (NFID)

The National Flood Information Database (NFID) was jointly developed by Risk Frontiers and Willis Re Australia for the Insurance Council of Australia. It comprises a database of flood hazard information – flood height as a function of ARI - at street address resolution for communities across Australia with significant numbers of residential properties at risk to riverine flood. Its development has been underwritten by the insurance sector and represents a significant commitment to dealing with the risk posed by riverine flood.

NFID is derived from the best quality available data (that is, flood modelling/mapping, Digital Terrain Models (DTM), and address location data). No hydrological or hydraulic flow modelling is undertaken by Risk Frontiers or Willis Re[19]; in this respect, the starting point for NFID is the output of modelling studies by specialist hydraulic and hydrological engineers in the form of maps, flood surfaces, flood study reports, etc. The flood data are processed and combined with DTMs and geo-located address data to estimate the frequency and depth of flooding for each address point.

The decision to use City or Local Council flood information was made expressly to avoid inconsistencies between flood maps used for land-use planning decisions and those used for underwriting purposes.

For those catchments where only the 100-year ARI flood extent is available – this is the case for many catchments in Victoria – addresses are rated as being either within or outside of this flood extent.

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[19] Some modelling decisions are peer reviewed by third-party consulting engineers.

A confidence rating is attached to each address entry based on age and resolution of the DTM, particular flood study and type of data available: flood extents, flood depths at one or several ARIs.

NFID is being delivered in several stages and has an ongoing maintenance program to incorporate changes in property exposures, new and revised flood information and improved digital terrain or street address datasets.

Figure 6 shows the breakdown of addresses covered by NFID and the newly released Flood Exclusion Zone™ database as at August 2012. Risk Frontiers' FEZ™ maps all addresses to either within or beyond the extent of flooding in a Probable Maximum Flood (PMF).
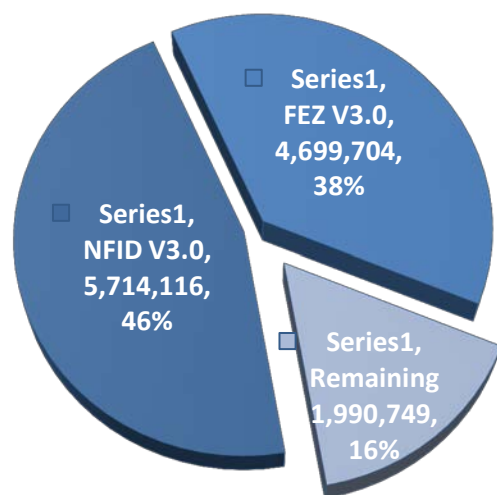

Figure 6: The number of addresses in NFID, those identified by FEZ™ as located *beyond* the extent of flooding in a PMF and the remaining sub-set of addresses which while located on a floodplain have no detailed flood risk information. On-going research is reducing the so-called remaining addresses.

The collection of flood information underlying NFID has been ongoing since the late 1990s. Most State or Local Governments bodies and/or Flood Plain Management Authorities have been forthcoming in their provision of flood information with a view to encouraging the availability of riverine flood insurance. A few councils have refused to provide information for a litany of reasons. Nonetheless we believe NFID already captures more than 80% of the flood-prone properties in the country and together with FEZ™ over 80% of all addresses in the country.

Risk Frontiers also maintains its own proprietary dataset of flood information for the major catchments on the eastern seaboard. For our purposes here, this database can be considered a subset of NFID.

5.4.2 *Validation of NFID*

Whenever possible, Risk Frontiers validates NFID. In the case of flooding, the 2011 inundation in Brisbane and Ipswich offered such an opportunity. Figure 7 compares the extent of the January 2011 flooding and the January 1974 flooding with the NFID flood surfaces interpolated to match the height of flooding at the Brisbane River City Gauge (4.46 m above AHD (Australian Height Datum) for the January 2011 event). The height of the flood in 2011 at the Brisbane City Gauge was 1m lower than in 1974. Close agreement between the observed flood extent and modelled boundaries is gratifying especially as the flood surface data used here was some *30 years old*[20]. More recent NFID contains newer flood studies created for the Brisbane City Council.

Although no two floods are identical – the pattern of rainfall in 1974 was different from in 2011 and there is also the questionable management in 2011 of the Wivenhoe Dam (van den Honert and McAneney 2011) – the extent of flooding downstream was *grosso modo* the same. The agreement of the flood extent in the 1974 flood and the 2011 flood brings home the statement made by Van der Vink et al. (1998) that we know where the most-at-risk areas are located already. The lack of appetite for pre-disaster risk reduction in this country cannot be sheeted home to a lack of knowledge.

Using NFID, we can estimate the national numbers of homes at high risk – say exposed to over ground flooding in a 100-year ARI event – to be around 150,000 addresses. Many of the land-use planning decisions that allowed these homes to be built were made before the availability of modern flood mapping and for reasons that at the time made perfect economic sense in the absence of flood information. However, there can be little excuse today for the continued development of the floodplain in ways that do not consider the latent risk.

Knowing that a home is located within the 100-year ARI flood extent, for example, doesn't provide much information about how deep the water might be or what might happen in less or more frequent floods. In the case of flooding, insurance has to be mindful of sensitivity of the local flood height to ARI.

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[20] Note that since the Version 3.0 NFID release, this data has since been updated by more recent flood modelling undertaken in 2009 by the Brisbane City Council.
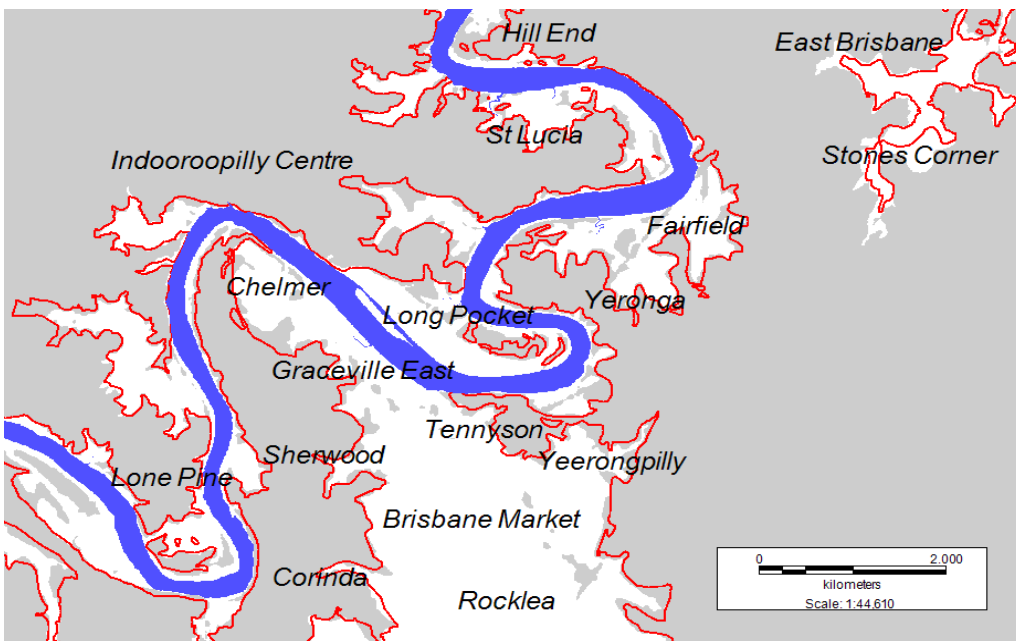
Figure 7: Comparison between actual extents of flooding in January 2011 (Top, red line) and January 1974 (Bottom, red line) as released by the Brisbane City Council. The areas in white indicate the extent of flooding as modelled by NFID (Version 2.4 and earlier) after water levels were matched at the Brisbane River City Gauge for the January 2011 flood. Dark blue areas depict the normal channel when the river is not in flood.

5.5 Risk Frontiers' FloodAUS Riverine Flood Loss Model

Risk Frontiers' FloodAUS loss model is a probabilistic model for pricing flood losses in Australia. Whereas NFID indicates the frequency of flooding at individual addresses, FloodAUS estimates damage costs for insurer portfolios. It generates a catalogue of plausible event losses and uses these to derive AEPs as well as other insurance-relevant statistics. FloodAUS uses high resolution flood modelling data, either from NFID for licensed users or Risk Frontiers' own proprietary databases, to represent the hazard as the average annual probability of flood water depths at individual addresses.

Historical datasets of flood damage and/or claims information have been analysed to derive relationships between damage and over-floor level water depths for different types of residential construction. Unless otherwise specified, FloodAUS adopts an average floor height of 27cm, close to what is expected for 'slab-on-grade' ('slab-on-ground) construction.

Many of the larger losses possible arise from contemporaneous flooding on multiple catchments. FloodAUS includes inter-catchment correlations and the catalogue of simulated event losses includes both those which span only one catchment and joint events spanning two or more.

Also estimated are post-event extra costs such as accommodation and clean-up.

5.6 Development of National Residential Portfolio

A postcode-level national residential building and contents portfolio was developed specifically for this project. It comprises all residential private dwellings from the 2011 Australian Census (Australian Bureau of Statistics (ABS) – http://www.abs.gov.au/)[21]. The Census definition of private dwelling includes residences in caravan/residential parks, camping grounds, marinas, manufactured home estates and retirement villages (self-contained) (ABS – http://www.abs.gov.au).

We apply dwelling values at the State/Territory level using the average nominal values of new dwellings at 2011. These are calculated by dividing the value of residential building work completed within a season by the number of completions within the same season with relevant values taken from Building Activity reports (ABS – http://www.abs.gov.au).

The value of new dwellings reflects, among other things, the size of new dwellings. On average, these are larger than that of the total dwelling stock. We use the Crompton (2011) adjustment to account for the larger average floor area of new dwellings. This adjustment is required as values are applied to all private dwellings.

The value of dwelling contents was determined assuming a 70:30 split between dwelling and content values. We also assume 100% insurance penetration for residential building and contents.

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[21] The Census dwelling classification is similar to, but not the same as, the ABS standard classification. The ABS defines a dwelling unit as a self-contained suite of rooms, including cooking and bathing facilities and intended for long-term residential use (ABS – http://www.abs.gov.au).

5.7   Hawkesbury River Basin

The Hawkesbury River basin (Figure 8) located in New South Wales covers approximately 22,000 square kilometres. It incorporates Goulburn to the south and extends almost as far as Singleton to the north. The floodplain is arguably one of the most over-developed and at risk in Australia (Morrison and Molino, 2012).

Flood events in the basin are not tied to any particular seasonal pattern and can occur at any time of the year. The majority of the rainfall occurs during the warmer months (Figure 9) but the rainfall that produces severe flooding almost exclusively comes from 'east coast lows' (intense low-pressure systems) (NSW SES, 2005). These systems are more common during Autumn and Winter with a peak in June (Bureau of Meteorology (BOM) – http://www.bom.gov.au/). Since east coast lows occur on average several times each year off the eastern coast of Australia (BOM – http://www.bom.gov.au/) it is possible to have multiple flood events on the same river system within the same year (NSW SES, 2005).

The largest recorded flood in the Hawkesbury River basin since Europeans settled on the eastern coast of Australia was in June 1867 (see Appendix 2 for a detailed event description) and was caused by an east coast low. More recent floods in 1964, 1978 and 1986 resulted from similar weather systems (NSW SES, 2005). Table 5 (from Morrison and Molino (2012)) shows the history of recorded floods in the basin. It is interesting to note that there has not been a 40-year ARI flood or higher since 1961.

Figure 10 shows the variation in total monthly rainfall over the period 1951 to 2000. During this time, there have been five events with a 30-year ARI or higher (Table 5). These floods occurred in the following months: 1990 (August); 1978 (March); 1964 (June); 1961 (November), and 1956 (February). All of these floods are reflected in high total monthly rainfall values (Figure 10).

Table 5: Hawkesbury River basin recorded flood history (source: Morrison and Molino 2012).

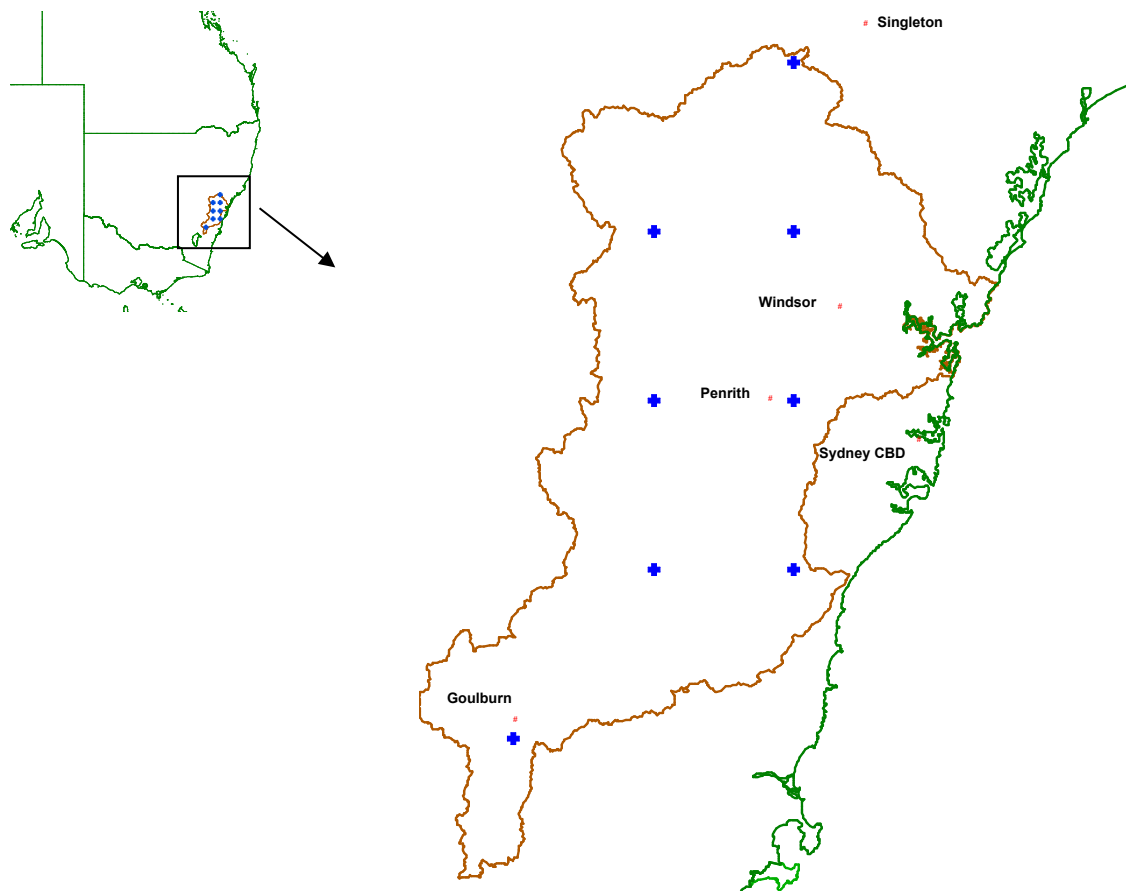| ARI (years)	Penrith (m AHD)	Windsor (m AHD)	When occurred
5	20.1	11.1	1992, 1986, 1975, 1956, 1952 & 11 other times
30	23.9	13.3-14.5	1990, 1978, 1964, 1956 & 12 other times (8 times 1806-1819)
40	24.4	15.0	1961, 1799
100	26.0	17.2	Not occurred
200	26.9	18.6	1867
500	27.6	20.3	At least once before 1788
1000	28.5	21.7	No record
PMF	32.1	26.4	No record

Figure 8: Hawkesbury River basin (brown outline). Blue crosses are the 0.5° grid locations within the Hawkesbury River basin.
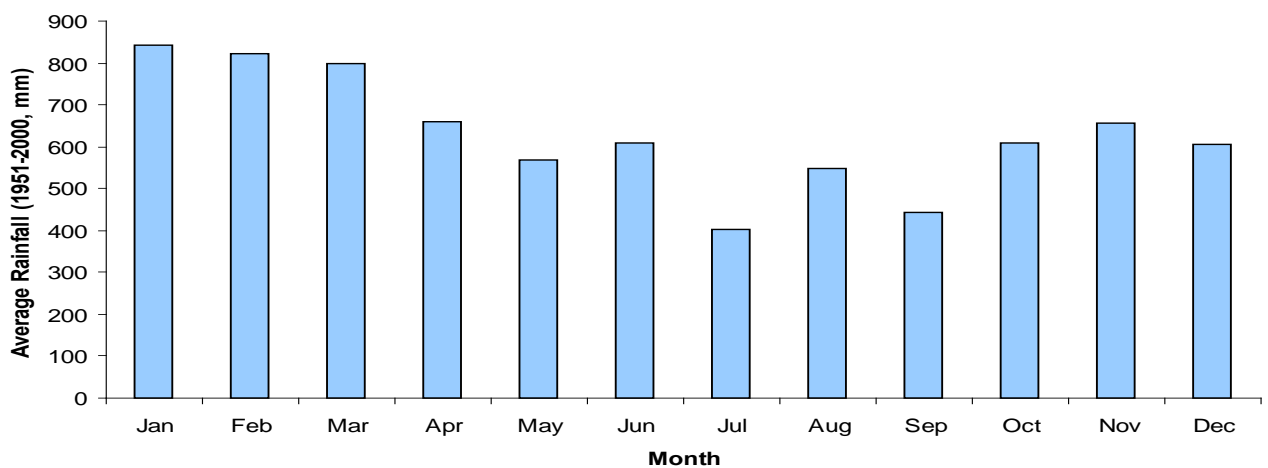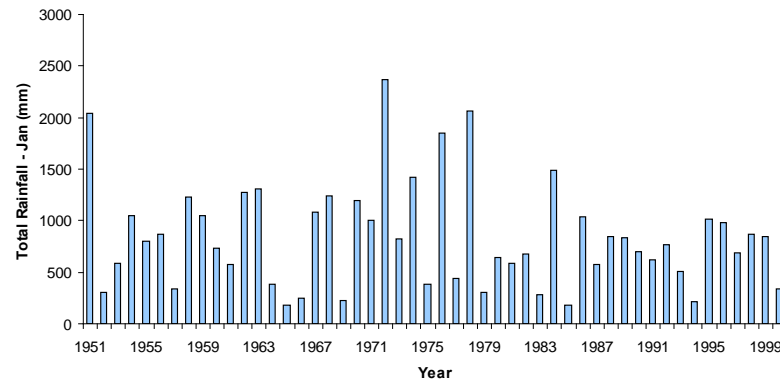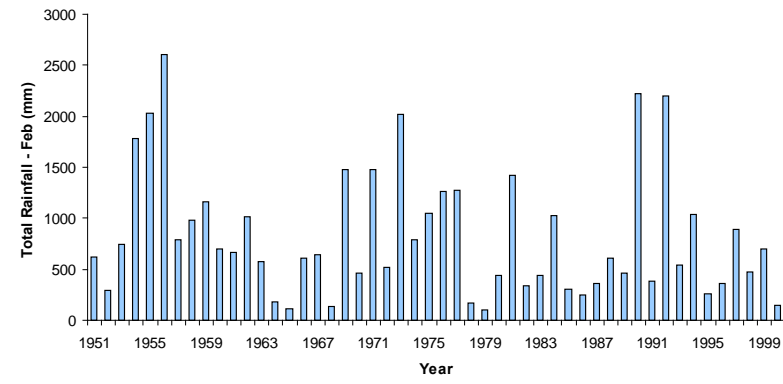

Figure 9: Monthly rainfall (mm) in the Hawkesbury River basin averaged over the period 1951 to 2000. Values are derived from an analysis of V1.1 of the Global Precipitation Climatology Centre (GPCC) VASClimO 50-year 0.5° precipitation climatology (following Beck et al. (2005)). The 0.5° grid locations that were analysed are shown as blue crosses in Figure 8.
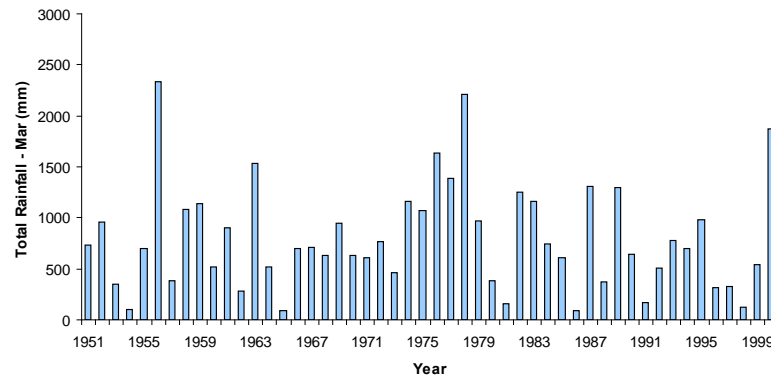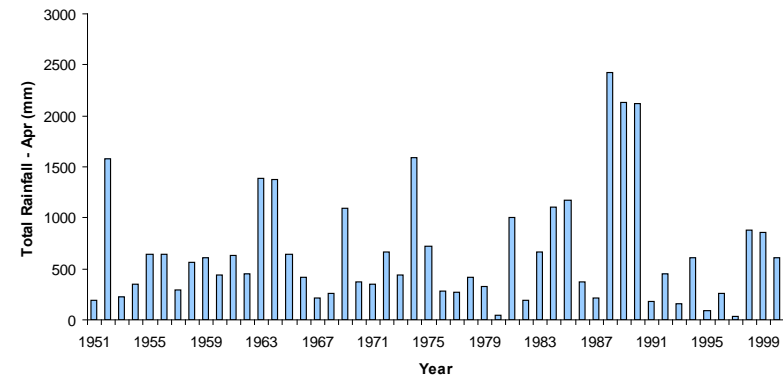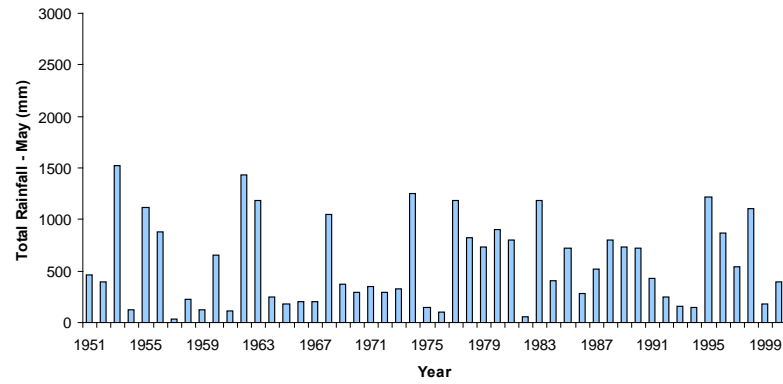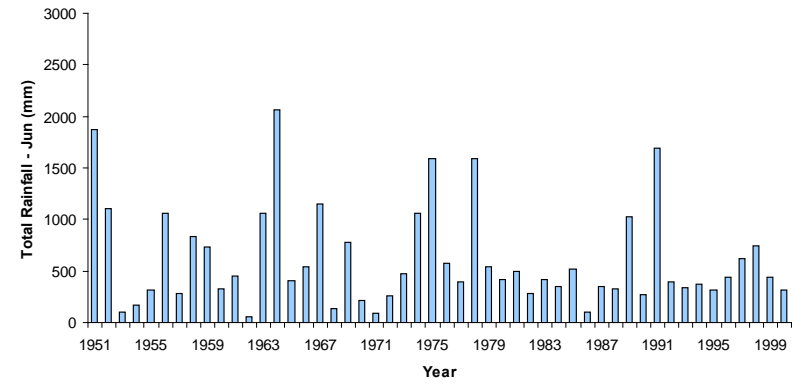
Jan

Feb

Mar

Apr
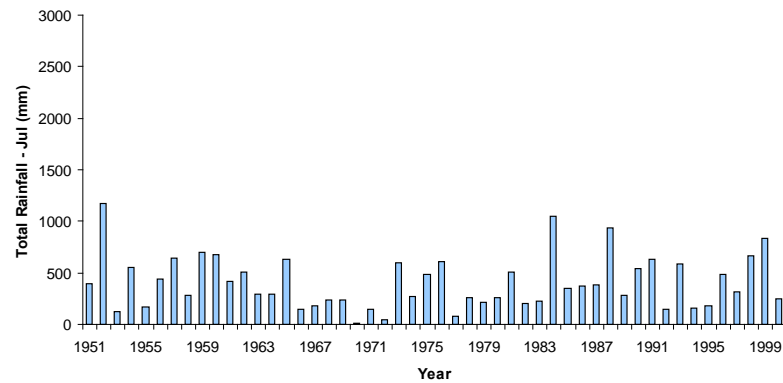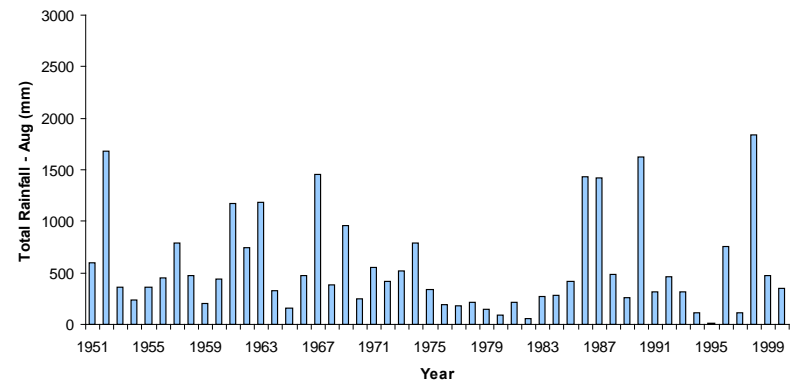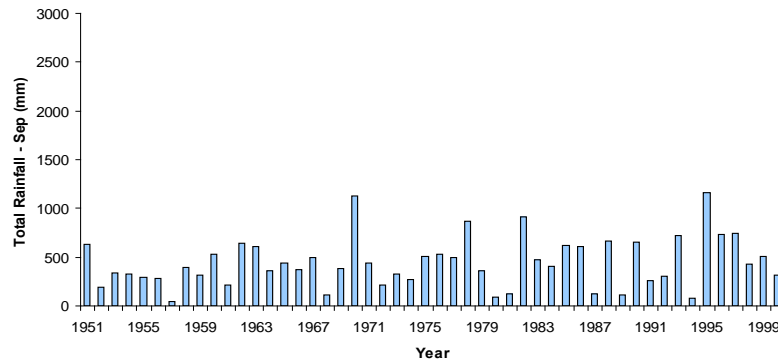
Figure 10: Total monthly rainfall (mm) in the Hawkesbury River basin over the period 1951 to 2000. Values are derived from an analysis of V1.1 of the Global Precipitation Climatology Centre (GPCC) VASClimO 50-year 0.5° precipitation climatology (Beck et al. 2005). The 0.5° grid locations that were analysed are shown as blue crosses in Figure 8.

5.8. Hypothetical Sydney flood CAT Bond

Modelled losses to the national residential market portfolio in the Hawkesbury River basin have been generated using FloodAUS. Figure 11 shows the postcodes (purple shading) within the Hawkesbury River b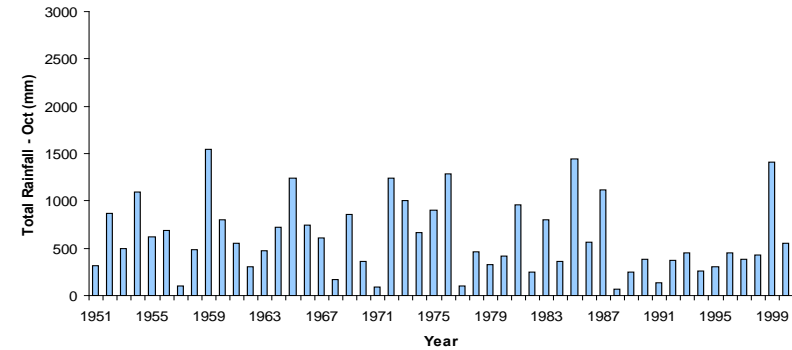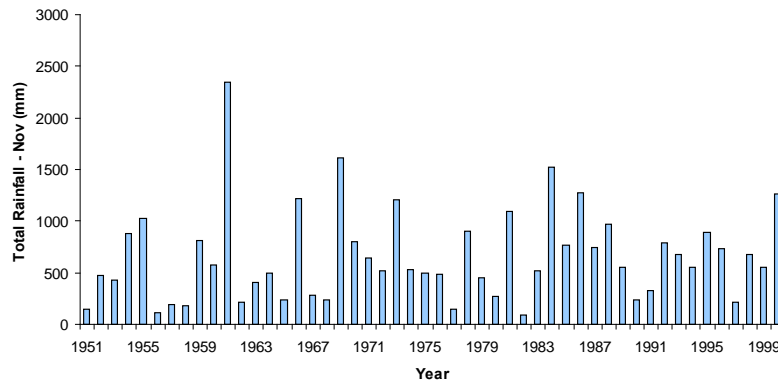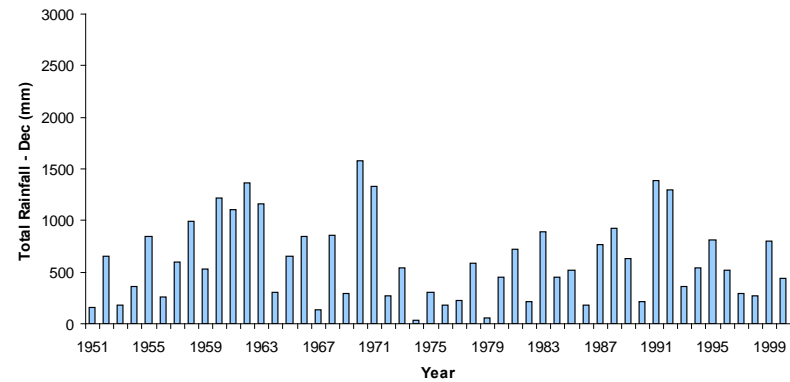asin that are within the FloodAUS model domain. The basin boundary is outlined in brown and the major rivers shown in blue.
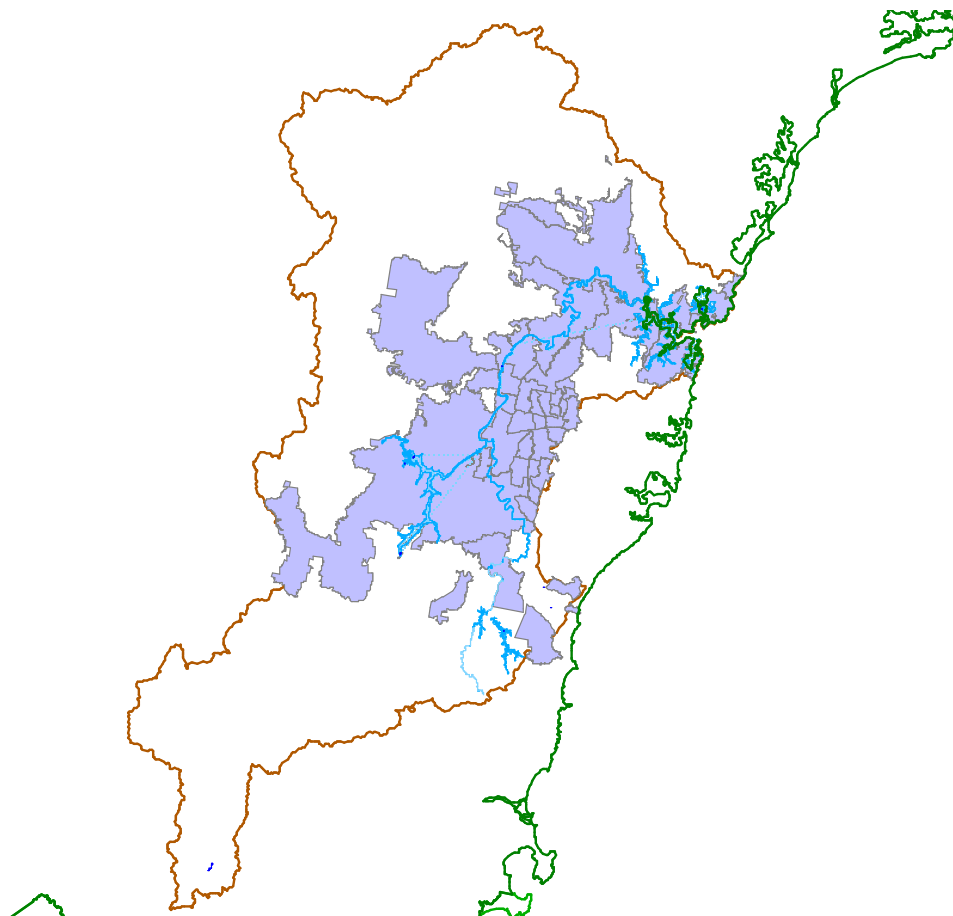
Figure 11: Modelled postcodes (purple shading) and major rivers (blue outline) within the Hawkesbury River basin (brown outline).

The main attributes of the flood bond and assumptions underlying our pricing calculations are given in Table 6. We modelled losses assuming the floor height of all buildings was the default value of 27cm and repeated the analysis assuming 1m and 2m floor heights. Increased floor height has little effect on the layer value but the benefit of this is evident in the much lower attachment points of the layer. The layer value is the principal raised through the issue of securities to investors and the estimated fixed transaction costs cover investment bank, legal, modelling, and rating agency fees.

Coupons are floating rate notes in the form of a spread above collateral return (the usual reference rate being the LIBOR (London Interbank Offered Rate)). For simplicity, we assume the trust proceeds (i.e. the principal) earn the reference rate. Each quarter,

and in the absence of an event that triggers the bond, investors receive the premium paid into the SPV plus the reference rate.

Table 6: Flood bond attributes.

	Default floor height (27cm)	1m floor height	2m floor height
Portfolio:	National residential building & contents		
1 – 0.4 per cent AEP layer value ($US):	$600 million	$604 million	$524 million
Expected loss:	0.66 per cent (66 basis points (bp))	0.69 per cent (69 basis points (bp))	0.65 per cent (65 basis points (bp))
Trigger type:	Indemnity		
Bond term:	4 years		
Fixed transaction costs:	$US2 million		
Premium & coupon payments:	Quarterly in arrears		
Coupons:	Spread above collateral return		

We have chosen an indemnity trigger but we could also develop parametric or modelled loss triggers for our hypothetical bond.

It is useful to calculate the effective rate-on-line (ROL) for this hypothetical bond and to compare this cost with traditional reinsurance. The ROL is simply a ratio of the premium to the layer value. To estimate this we first need an approximate value for the premium paid by the sponsor to the SPV. Despite there being many other determinants for the spread, the main drivers are the expected loss of the layer and the probability of loss. The return on the bond (the spread above collateral return) can be approximated by comparison with previous CAT bond transactions.

One other factor needs to be taken into consideration: investor demand for an Australian risk is likely to be high thereby lowering the required spread because of the diversification opportunities it would offer investors. Previous CAT Bond transactions reflect this specific risk price variability with Japanese earthquake bonds, for example, generally being priced lower than California earthquake bonds. This is because investors prefer to limit their exposure to any one type of risk (e.g. California earthquake) or demand higher yields for accepting the risk. In principle, there should be less variability in spreads as the investor base continues to widen.

The overall risk-return profile is shown in Figure 12. To account for the specific risk price variability only outstanding CAT Bonds covering European wind, Japanese typhoon and earthquake and US Pacific Northwest earthquake are included in Figure 12. These bonds have typically been priced lower than average and are therefore likely to more closely reflect (though still overestimate) the required spread for an Australian bond.

So for our annual expected loss of 65 to 70bp, what does the market say? From Figure 12 the approximate annual spread above collateral return for the flood bond should be around 330bp for all floor height scenarios. This leads to a ROL of approximately 3.5% once fixed transaction costs are taken into account. This ROL, although expected to be an upper bound, is in excess of the cost of traditional reinsurance that might come in at around 2 to 3% for the same layer. Whether the difference is too much to pay for guaranteed security is a business decision for insurers.
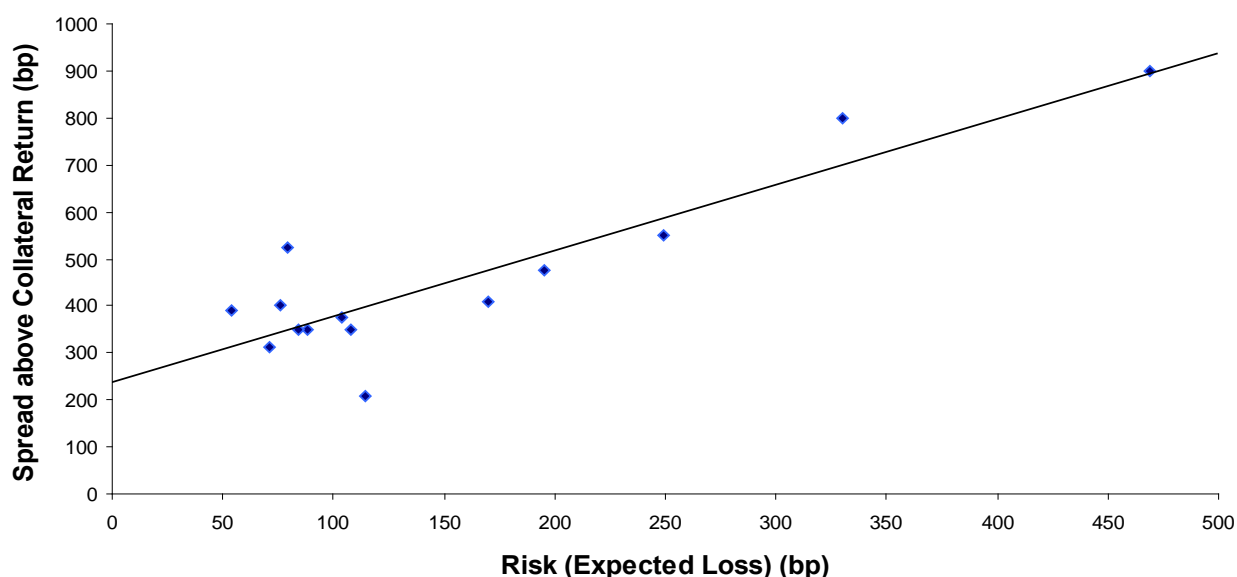

Figure 12: Non-life, non-US and non-multi-peril outstanding bond (i.e. bonds that have not yet matured) spreads for a given risk level. The data includes the following risks: European wind, Japanese typhoon and earthquake and Pacific Northwest earthquake (data source: Swiss Re, 2012b).

5.9   Conclusions

After reviewing the attributes of CAT Bonds, our case study centred on a hypothetical Sydney flood CAT Bond transferring insured residential flood risk in the Hawkesbury River basin to the capital markets. The methodology is easily extendible to Brisbane or any of the other main peril exposures throughout Australia.

Is another Australian CAT Bond likely in the foreseeable future? The oft-repeated argument against is that they are too expensive and there is currently ample reinsurance capacity in Australia. This may be true, though we emphasise the point that CAT Bonds remain one of the very few sources of triple-A rated security. And while an insurer can minimise counterparty credit risk, by spreading the risk among several reinsurers, there are limits to this diversification as all large reinsurers will carry at least some exposure to the relatively small handful of global peak perils.

The continued emergence of large concentrations of development in areas of very high-risk is expected due to increasing exposure. CAT Bonds can help manage these concentrations by diversifying risk in the capital markets. They complement the traditional reinsurance market by broadening capacity. However, these instruments should in no way detract attention from the need to reduce vulnerability in the future. As

we have shown, measures such as increased floor heights can dramatically reduce the flood risk in exposed areas and the need to transfer it.

6. GAPS AND FUTURE RESEARCH DIRECTIONS

As with the rest of this study, our interest here is in extreme weather and not the inexorable changes anticipated with rising global air temperature such as sea level rise. In this context two further studies are advocated:

Evaluating and Pricing uncertainty. It is often proposed by those advocating urgent political action in response to global climate change that the uncertainty in model projections should not inhibit necessary decisions. Clearly there are many decisions that come under the *no regrets* category, a case in point being the avoidance of further development of floodplains or at least in ways that ignore the risk of flooding. Risk-informed land-use planning would confer benefits regardless of the trajectory of global climate change.

The implications of a warming climate on the frequency and severity of many severe weather phenomena are currently very unclear and thus decision-making around this issue remains difficult. If *decision-making under uncertainty* is to be distinguishable from *decision-making under ignorance*, then we need some understanding of the scale of the uncertainty. And unfortunately in this country the practice of relying on a single or small ensemble of models mutes this understanding.

As we have seen in the case of projections of the basin-wide North Atlantic hurricane activity under a warming climate, model output and its imputed consequences for damage vary widely between the climate models used to set the boundary conditions of the down-scaling (Bender et al., 2011; Crompton et al., 2011). We can consider these models as providing different views of the future based on different assumptions and views of the underlying science. The various model outputs could be studied to estimate the magnitude of this attendant uncertainty and, bearing in mind that in the financial sector uncertainty comes with dollar signs attached, its price.

We propose that uncertainly be studied in the context of US hurricane based on the latest round of AR5 model outputs. Doing so would serve to put some bounds on the level of uncertainty and some constraints on decision-making in respect of severe weather events whose frequency and magnitude are likely to be changed in a warming climate. This uncertainty is also a key ingredient in any Real Options analysis that examines the value of waiting before committing to a firm course of action. In other words, the value of learning before acting.

Designing a natural disaster pool for Australia. We had anticipated that in reviewing various residual market mechanisms that we might see a clear way forward for the Australian government to deal with pockets of exposure that may become uninsurable particularly in the case of flood and/or bushfire. Unfortunately the experience is mixed with systems shown to be either unsustainable in an insurance sense and/or having little impact on curbing the growth of at-risk population and assets. Many schemes do not have the reduction of risk as part of their mandate and few consider climate change seriously. If a residual market scheme is just a complicated mechanism of putting this risk back to the government and thus to all taxpayers, it seems hardly worth the effort. Certainly in the US there is ongoing debate as to the role of government in insurance. In our view this topic requires a deeper examination than could be accorded under the current study.

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APPENDIX 1: THE COST OF CAPITAL

The primary objective of private enterprises such as insurance companies is to deliver greater wealth to their shareholders than the latter would gain from investing their funds in a bank, say or purchasing government bonds. They provide services and products to individuals and organisations in return for a fee, the value of which is constrained by competition and the preparedness of sufficient customers to voluntarily pay this fee for these services or products (Walker, 2010). In attempting to calculate a fair premium for catastrophe cover, insurers must determine the total costs involved in the provision of that cover, including adequate return on investment capital. Return on capital quantifies how well a company generates profits relative to the capital it has invested in its business. Failure to include all costs in their pricing would leave them vulnerable to insolvency in the event of extreme catastrophes.

Legislators in the US have failed to grasp the implications of catastrophe loss exposure. In Florida, for example, the 4-170.003: 2:1 premium to surplus ratio, 5% profit restrictions, did not reflect the capital structure or risk load of the catastrophe insurance market. It allows neither for the accumulation of sufficient capital to cover the Probable Maximum Loss (PML) nor for adequate return on investment.

Musulin (2004) demonstrated the difference in capital investment requirement between catastrophe insurance and non-catastrophe lines of business, based on Florida's Rule 4-170.003, where average annual losses are used as the criterion for measuring risk exposure. According to Florida legislation, if a catastrophe insurer had an expected annual loss of $1 million, only 5% of that expected loss could be paid in investment returns, i.e. a sum of $50,000. In fact the exposure of such a company in the face of a natural disaster would not be the expected annual loss but would be closer to $10 million. Since the investors of the $10 million capital required by the insurer would be restricted by legislation to receive returns in excess of $50,000, they would actually receive only 0.56% profit on the extra $9 million they had invested (Musulin, 2004). This is not an acceptable rate of return for investors.

The legislation in Florida has forced insurers to purchase reinsurance to cover their true exposure, and for state entities to borrow to settle catastrophic losses (Musulin, 2004). There are two main issues to be considered with regard to Florida's presumed profit factor rule:

- the calculation is based on expected annual losses and takes no account of the capital required to cover the PML which would be many times greater than the average loss;
- the legislated allowable profit is not adequate to attract investors to the catastrophe market. Legislation needs to be adapted to encourage insurers to raise internal capital rather than buy reinsurance which is much more costly.

Catastrophe insurers must be allowed to determine how much capital is required to settle claims, maintain solvency and credit rating and to comply with regulatory requirements. They must also be allowed to offer a competitive return on capital investment because if they cannot attract enough surplus funds they may be forced to purchase more reinsurance. In order to determine the amount of capital required, both insurers and legislators need to be aware of all costs including exposure liability (each additional policy adds a liability that must be covered), allocation of risk capital to pay

losses that exceed income from premiums, costs of catastrophe modelling and all costs involved in the marketing and selling of insurance (Czajkowski et al. 2011).

The types of capital investment that insurers may secure include Catastrophe Bonds, contingent surplus notes, exchange-traded catastrophe options and catastrophe equity puts and swaps (contracts between a company and third party to exchange assets or cash flows periodically to spread risk) (ISO http://www.iso.com/About-ISO/Overview/About-ISO.html).

- Catastrophe Bonds allow the writing down of the liability and for payments of interest or principal to be retained by the insurer to settle claims in the event of a catastrophe.
- Contingent surplus notes allow for the insurer to purchase the right (either unconditionally or subject to certain conditions) to issue in the future at pre-set terms in exchange for cash. The surplus notes can then be issued in the event of catastrophic loss.
- Exchange-traded catastrophe options are contracts giving the purchaser right to cash payment if catastrophe losses reach a specified level within a set period (called the strike price). Insurers can buy these options from investors to hedge risk. If losses exceed the strike price, the insurer is paid by the investor the contracted amount.
- Catastrophe equity puts allow insurers to sell pre-specified stock at pre-negotiated prices to the seller of the option, once catastrophe losses exceed the contracted level within the specified term.

APPENDIX 2: JUNE 1867 HAWKESBURY RIVER FLOOD

The 1867 flood on the Hawkesbury River basin remains by far the largest recorded since Europeans settled on the eastern coast of Australia. Although the basin was far less densely settled in 1867 than at present, the effects of this flood were extraordinary even then.

Large areas were covered by water, including Emu Plains and Castlereagh; from Yarramundi to Pitt Town Bottoms, McGraths Hill and up the South and Eastern Creek valleys. Windsor, Richmond, Pitt Town and other settlements became islands surrounded by floodwaters. Parts of these and other towns, as well as most rural areas in between the towns were inundated during the flood, which lasted for several days. Figure A1 shows the extent of the flooding.

The rain commenced on Tuesday, 18 June 1867, with the river breaching its banks on Thursday 20 June. The following is a descriptive excerpt from the *Sydney Morning Herald* published on 24 June 1867:

> *The flood in this district is said to be by far the highest which has occurred since its settlement by Europeans. The town of Windsor itself is almost entirely submerged, and the country for miles around is under water.*
>
> *The expanse of flood is so great, that everybody is astonished at the tremendous accumulation of water, and it will seem incredible to all who have not actually seen it. Places which since the settlement of the colony, have never known to be flooded are now lost to view. The plain on which Windsor is partly situated unites with South Creek and Eastern Creek to form a vast inland sea over the surface of which when the wind has been high the broken crested billows roll with as much force and volume as they do during moderately squally weather in Sydney Harbour. A boat may now be taken through deep water from Riverstone to the Blue Mountains - a distance of about 15 miles; and from Hall's at Pitt Town to the Kurrajong - some twenty miles.*

The flood was well documented because of its size, and peak levels were reported at several locations along the river. In Windsor, the best known record is on a wall in Thompson's Square. It is indicated by a plaque and is often referred to by local people whenever the question of 1867 floodwater levels is raised. However, the origin of the mark is unknown. Some other records are known to be of secondary sources, i.e. not derived from observation or debris marks, but transferred from other 1867 levels.

For example, a plaque in the grounds of Windsor School states that the level was transferred from the mark in Thompson's Square. John Tebbutt recorded a level of 19.7m AHD, about 0.3m higher than the mark in Thompson's Square, and this reading is considered the most reliable record. This is approximately 19.7m above sea level, and flood water would have overtopped the deck of the existing Windsor Bridge by more than 12.7m. Water is estimated to have reached a height of 26.9m AHD at Penrith.

The peak inflow of the 1867 flood was approximately 40 per cent of the PMF at Warragamba (ERM Mitchell McCotter, 1995). The water depth was about two metres higher at Windsor than the most recently estimated 100-year ARI event and about 30 per cent greater in volume.

Figure A1: Map showing the extent of the 1867 flood (source: NSW SES 2005).

This event is a good example of how real floods have various probabilities at different locations. Based on statistical analysis of flood levels at Penrith and Windsor, the 1867 flood had a 0.59% and 0.36% AEP respectively. At Camden it was estimated to have an AEP as high as 6.7% (Water Resources Commission 1986). These differences in flood peaks mainly arose from the distribution of rain across the catchment which can vary widely (NSW SES 2005).

Meteorological data was not as widely available in 1867 as it is today. Exactly where the flood-producing rain fell is difficult to determine, although available flood and rainfall data provide some clues. Similar to other flood events on the Hawkesbury River, this flood occurred as a result of an intense east coast low (NSW SES, 2005).

Records at Camden indicate that the 1867 flood has been exceeded there on five occasions and the Upper Nepean was therefore unlikely to have been the main contributor in 1867. Reliable rainfall records at Windsor were unavailable but readings from surrounding areas show that falls were not outstandingly heavy east of the Blue Mountains (Bracewell and McDermott, 1985). It thus appears that the Warragamba River and possibly the Grose River were the principal sources of the huge volume of water involved.

It is difficult to find any information regarding the number of homes and businesses lost as a result of this disaster; however, it is clear from the extent and severity of the flood that a very large number of buildings and properties must have been destroyed or damaged. Settlers from miles around Windsor were brought into the town after losing their homes and all of their property.

A *Sydney Morning Herald* article dated 24 June 1867 details the extent of the flooding and makes mention of many submerged buildings, particularly in Windsor and surrounding areas. The same article discusses the interruption of telegraphic communication due to lines damaged between Blacktown and Windsor and on the line via Bathurst, Mudgee and Murrurundi, and mentions the loss of stock including horses.

> *The eleven family members killed were two wives and 9 children [who were] caught on a roof top. The two husbands and one boy were saved by swimming to a tree but their attempts to save the others failed. The three survivors were later rescued by boat.*

Newspaper articles clearly describe the high flow velocities and the speed with which the water rose, trapping people on roof tops and high ground.

A large number of people became stranded because they were unaware of how high the floodwaters would rise. The following excerpt from the same 24 June 1867 *Sydney Morning Herald* report details the situation on the ground and the community's lack of knowledge concerning the potential flood risk at the time.

> *The volume of water has astoundingly increased since Thursday. On Friday many buildings in the town [Windsor] were in jeopardy and on Saturday the whole township, excepting the two or three patches already named, was overwhelmed. The water rose very rapidly, and the inhabitants were in dread of being swamped altogether. Most of them thought that they would have to betake themselves to the Terrace, the nearest and most accessible town in the Blue Mountains. The water continued to rise slowly during the night, but at 5 o'clock yesterday (Sunday) morning it was at a standstill, and by 8 o'clock the water had gone down three or four inches.*

The *Sydney Morning Herald* report talks about the rescue efforts in Windsor carried out using four boats supplied by the government and Police and some private boats supplied by people in the district. People were rescued from the upper windows, ridge poles and roofs of their homes and taken to safety. Continuing rising water meant that some people had to be evacuated for a second time.