The Australian Great Flood of 1954: Estimating the Cost of a Similar Event in 2011

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ABSTRACT

As in many other parts of the globe, migration to the coast and rapid regional development in Australia is resulting in large concentrations of population and insured assets. One of the most rapidly growing regions is southeastern Queensland and northern New South Wales, an area prone to flooding. This study reexamines the Great Flood of 1954 and develops a deterministic methodology to estimate the likely cost if a similar event had occurred in 2011. This cost is estimated using council flood maps, census information, historical observations, and Risk Frontiers' proprietary flood vulnerability functions. The 1954 flood arose from heavy rainfall caused by the passage of a tropical cyclone that made landfall on 20 February near the Queensland–New South Wales border, before heading south. Responsible for some of the largest floods on record for many northern New South Wales' river catchments, it occurred prior to the availability of reliable insurance statistics and the recent escalation in property values. The lower-bound estimate of the insurance loss using current exposure and assuming 100% insurance penetration for residential buildings and contents is AU$3.5 billion, a cost that would make it the third-highest ranked insured loss due to an extreme weather event since 1967. The corresponding normalized economic loss is AU$7.6 billion but the uncertainty about this figure is high. The magnitude of these losses reflects the accumulation of exposure on the floodplains. Risk-informed land-use planning practices and improved building regulations hold the key to reducing future losses.

1. Introduction

Weather-related hazards dominate Australia's short loss history from recorded natural disasters. They account for 93% of building damage between 1900 and 2003 (Crompton et al. 2008) with tropical cyclones and floods being the most deadly after heat waves (Coates 1996). With some 50% of Australians now living within 7 km of the coast (Chen and McAneney 2006), the concentration of population in regions prone to flooding, storms, and tropical cyclones is increasing. Much of this development has occurred over a period of relative quiescence in terms of natural disasters (Crompton and McAneney 2008). The purpose of the current study is to estimate the insured loss if a widespread flooding event, which took place in 1954, recurred under 2011 societal conditions. We also attempt a rough estimate of the associated economic loss.

The accumulation of exposure on floodplains and failure to learn from past events was a feature of the losses from the large-scale flooding in Queensland in 2010/11 (van den Honert and McAneney 2011). This event cost insurers some AU$2.4 billion (see http://www.insurancecouncil.com.au/industry-statistics-data/disaster-statistics) despite only a few companies offering riverine flood risk for residential customers. These floods caused much greater losses to state and federal budgets, with the Commonwealth Government alone planning to contribute AU$5.6 billion toward the reconstruction program (Swan 2012). The area flooded included the Queensland state capital of Brisbane, a city that experienced even higher flooding in 1974 and larger floods again in the nineteenth century (van den Honert and McAneney 2011).

Although disaster losses are increasing, evidence across multiple jurisdictions and different perils shows that these increases are largely explained by changing societal factors, chiefly increases in population, wealth, and inflation [e.g., Pielke and Landsea 1998, 1999; Pielke et al. 2008; Crompton and McAneney 2008; Chen et al. 2009; Di Baldassarre et al. 2010; Barredo 2009, 2010; Crompton et al. 2010; see also other studies reviewed by Bouwer (2010)]. In short, there are now more people living in vulnerable places with more to lose. This is certainly the case for the region of interest for the present study, the Gold Coast region (GCR) of southeastern Queensland (QLD) and the Northern Rivers region

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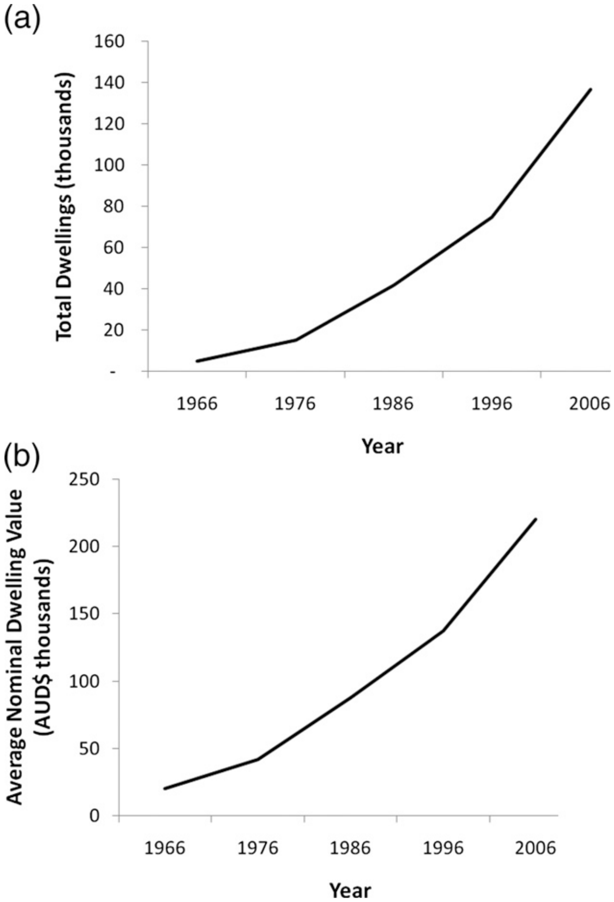

FIG. 1. (a) The number of dwellings in the Tweed Heads area and (b) average nominal new dwelling values (AU$, in thousands) as a function of time (data from the Australian Bureau of Statistics; see http://www.abs.gov.au).

(NRR) of New South Wales (NSW), which together comprise one of the fastest growing regions in Australia. The population of southeastern Queensland, for example, is expected to exceed 4 million by 2026 and to have an additional 754 000 dwellings by 2031 (Queensland Government 2009). In this regard, the region is fast becoming Australia's version of Florida. Figure 1a highlights the growth in the number of dwellings in the Tweed Heads area of the GCR and NRR, while Fig. 1b shows the contemporaneous increase in national average dwelling values over the same time period.

The historic riverine flooding scenario considered here was one of the largest flooding events experienced in the region since records began. It was caused by widespread and heavy rainfall associated with the passage of an unnamed tropical cyclone (TC137) that in February 1954 made landfall at Coolangatta and then tracked southward (Fig. 2). Because credible information on insurance losses in Australia from natural disasters has only been collected since 1967 (Crompton and McAneney 2008), there is no record of insured losses from this flooding event.

Before proceeding, it will be useful to make explicit our use of the term *risk*, which we define as a multivariate function of the *hazard* attributes—the depth and frequency of floodwaters in this case; the *exposure*—the spatial distribution of insured assets (e.g., residential dwellings) and their values; and their *vulnerability*—the cost of water damage as a fraction of the insured value and as a function of water depth. This conceptual framework underpins loss modeling as used by the insurance sector to inform the purchase of reinsurance, capital needs and premium pricing (Woo 1999; Grossi and Kunreuther 2005; Roche et al. 2009). The modeling can be either deterministic (scenario based) or probabilistic (considering a simulated catalogue of all plausible outcomes). In this paper we develop a deterministic loss estimation method using observed and modeled data on hazard, exposure, and vulnerability.

The reader should also be aware that in Australia, damage from most natural perils—earthquakes, tropical cyclones, bushfires, and hailstorms—is automatically covered in a homeowner's insurance policy and the level of noninsurance for buildings is only about 4% (see http://www.insurancecouncil.com.au). Riverine flood, however, has long been an exception to the rule but since the 2010/11 Queensland and Victorian floods and under pressure from the government, it is being increasingly included in standard policies (see the report "National Disaster Insurance Review," available online at http://www.ndir.gov.au/content/report/downloads/NDIR_final.pdf). For our study, we shall assume 100% insurance penetration for riverine flood cover for residential buildings and contents.

Our paper is constructed as follows: we first briefly describe TC137 and its impact at the time on local communities in terms of fatalities and property damage and, where possible, business losses. We then outline our methodology for estimating current-day (2011) losses that might result from the recurrence of such an event. This is followed by discussions of key results and limitations of our approach. The paper concludes with implications for land-use policy in and around floodplains.

2. Impacts of Tropical Cyclone 137

On 20 February 1954 the tropical cyclone referred to as TC137[1] made landfall just inside the QLD border at

[1] Tropical cyclones have been named in the Australian region from the 1963/64 season although some systems were named prior to this. The February 1954 event was not given an official name but is often referred to as TC137.

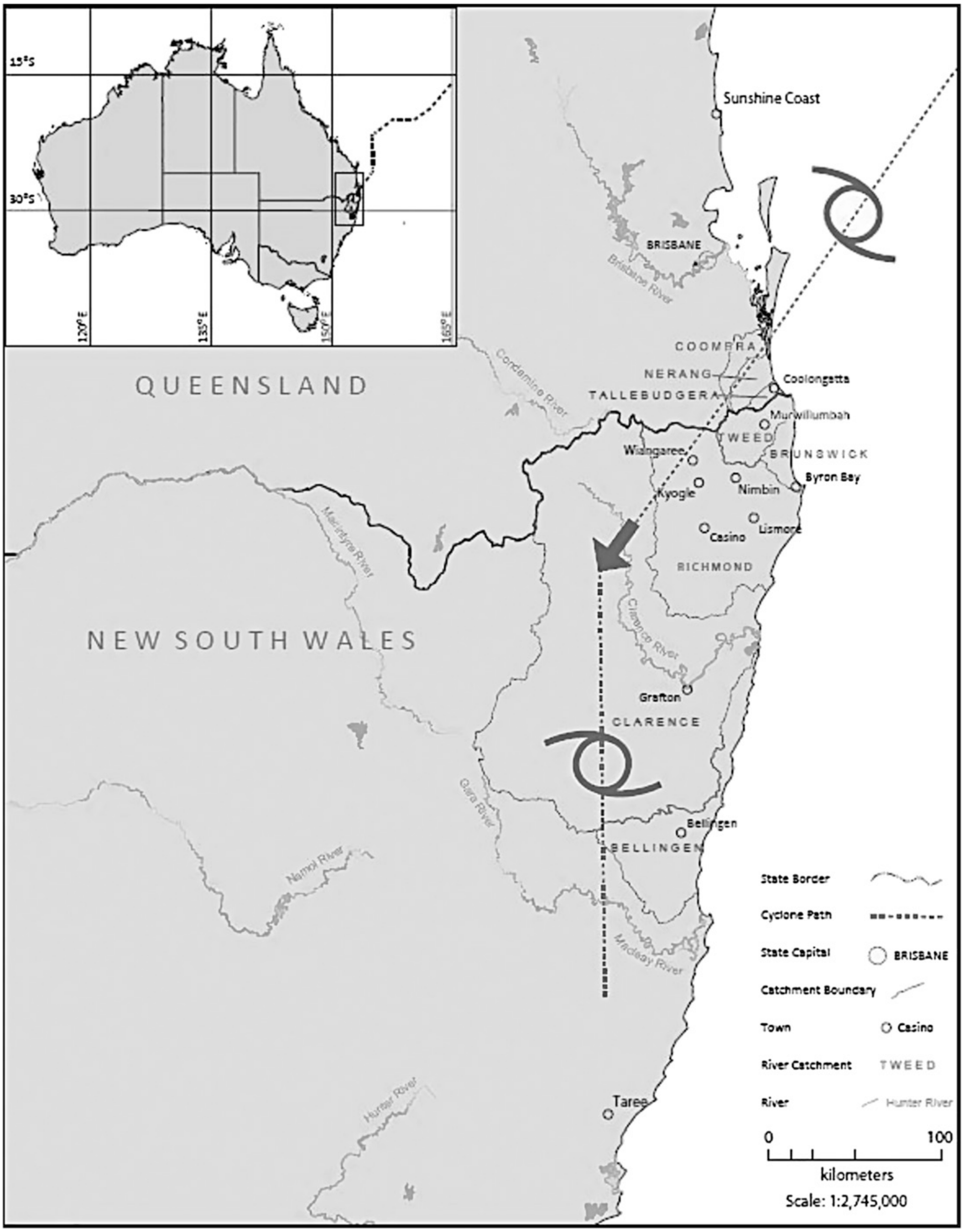

FIG. 2. Track of T137 (see map online at http://www.bom.gov.au/cyclone/images/TC137.gif).

Coolangatta with a central pressure of 973 hPa (BoM 2012). It then tracked southward (Fig. 2) as an Australian category 1 tropical cyclone (tropical storm on the Saffir–Simpson scale) causing widespread flooding and the loss of 28 lives (Callaghan and Helman 2008). Wind damage was limited and most losses were from riverine flooding. Rainfall from the event, commonly known as the Great Flood of 1954, produced the highest recorded flood levels to this day in almost all major rivers and creeks in the most impacted catchments.

It was the correlated flooding over a wide area that makes this event of interest. Springbrook, just inside the QLD border, received 900 mm of rainfall in 24 h (BoM 2012). The Nerang, Tweed, Brunswick, Richmond, and

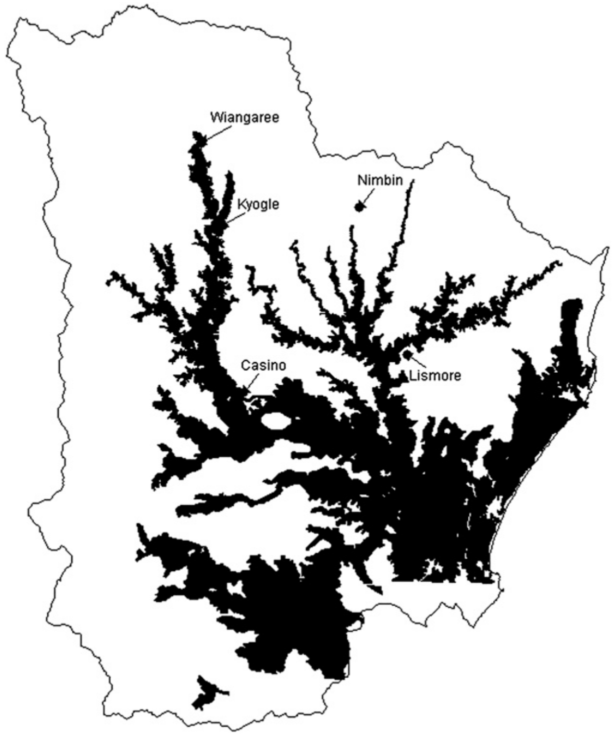

FIG. 3. Extent of flooding in the Richmond River catchment following the passage of TC137 (see map online at http://www.bom.gov.au/cyclone/images/TC137.gif).

Clarence catchments all flooded simultaneously (Fig. 2). The Richmond catchment was hardest hit and the extent of inundation is shown in Fig. 3. Most towns located within the Richmond catchment including Lismore, Kyogle, Casino, and Nimbin (Figs. 2 and 3) experienced their highest ever recorded flood heights and significant damage to dwellings, as did Murwillumbah (Tweed catchment) (Fig. 2). In Lismore 3000 people were left homeless (*The Daily Examiner,* 23 Feb 1954, p. 3), while in Grafton 700 homes were flooded (*The Daily Examiner,* 22 Feb 1954, p. 1). Damage to the Lismore business district was estimated at £2 million (*The Northern Star,* 25 Feb 1954, p. 2) in the currency of the time.

Large waves at Byron Bay (Fig. 2) broke through the sand hills and reached areas five blocks back from the beach (E. Wright 2010, personal communication). The surge took with it approximately 200 m of the fishing wharf and destroyed 23 of the 24 boats (*The Northern Star,* 25 Feb 1954, p. 1). At that time, fishing accounted for 20% of the town's employment.

TC137 knocked out power, telephone, and gas services that remained out of service for up to eight days. Damage to highways and trunk and main roads was estimated at over £1 million in the currency of the time. Landslides and floodwaters destroyed over 40 bridges in the area and 20 sections of the railway line to QLD were completely washed out. While losses to livestock proved not as high as initially feared, sugar cane, maize, and banana crops valued at several million pounds were destroyed (*The Northern Star,* 26 Feb 1954, p. 1).

We are not aware of any documented historical figure for the total economic losses and so estimate this by aggregating specific losses reported in various newspapers to obtain a figure on the order of AU$19 million (using an exchange rate of 2.5 Australian dollars = 1 British pound; http://fx.sauder.ubc.ca/etc/GBPpages.pdf). In what follows, we develop a ground-up loss estimation methodology to estimate the insured and economic losses if a similar event had occurred in 2011.

3. Loss estimation methodology

Our approach approximates the total insured loss (TIL) in 2011 values from our estimated residential losses for a 2006 portfolio of dwellings and an average ratio of total insured losses to residential losses across other flooding events for which we have data:

$$\mathrm{TIL} \approx R \times n \times (\mathrm{ML}_{2006} + \mathrm{AL}_{2006}), \tag{1}$$

where R is the ratio of the total insured loss across all lines of business—residential, commercial, and industrial—to the residential dwelling losses and n is a normalization factor used to adjust the modeled (ML_{2006}) and aggregated (AL_{2006}) nonmodeled residential losses based on 2006 data to 2011 societal conditions.

The aggregated nonmodeled loss (AL_{2006}) represents the K flood-affected homes that lie outside the geographical domain covered by modeled flood surfaces (hereafter referred to as the "modeled domain") but fall within the flooded catchments (hereafter collectively referred to as the "study domain"). Herein AL_{2006} is simply estimated as follows:

$$\mathrm{AL}_{2006} = K \times \overline{x}, \tag{2}$$

where $\overline{x}$ is the average modeled loss per dwelling (2006 values) for those dwellings within the modeled domain.

In what follows we provide descriptions and assumptions about individual inputs that collectively contribute to estimated loss components: flood hazard level, exposure distribution, building vulnerability, and floor height.

a. Average recurrence interval (ARI) of the 1954 flood

This is a difficult issue that we examine from a number of different perspectives. Our primary resources are the design flood surfaces modeled for various discrete ARIs—commonly only the 1:20, 1:50, and 1:100 year surfaces—as developed by consulting hydrologic and hydraulic engineers for key concentrations of exposure for some but not all local councils within the study area. These studies commonly use major flooding events of the past, such as the 1954 flood, to calibrate modeling assumptions and validate modeled outputs. The estimation of flood frequency depends heavily upon the availability of long-term quality river data (e.g., flow discharges and/or water levels) that can be sourced from local council reports. For the two most important catchments in our study area (Tweed and Richmond Rivers), the 1954 event is estimated to have an ARI of a 100-yr flood in the most recent hydrological and hydraulic engineering studies for the city councils:

- *Tweed River catchment*: The February 1954 flood is the largest flood on record (since 1916) in the catchment. The entire floodplain was heavily inundated. At Chinderah located at lower Tweed River, the 1954 flood produced flood levels similar to the 100-yr ARI flood (Tweed Shire Council 2009). The majority of catchment settlement is located on the lower Tweed River.
- *Richmond River catchment*: The February 1954 flood is the largest and most destructive flood on record in the catchment since records began in 1887 (Richmond River County Council 2010).

At the northern extent of the study domain where TC137 made landfall (Coomera, Nerang, and Tallebudgera catchments in the Gold Coast region), the flood level at Clearview (on the Nerang River central to the Gold Coast region) from the February 1954 event is the third highest (9.83 m) since records began in 1920, only slightly lower than those of the January 1974 flood (10.22 m) and the June 1967 flood (10.18 m) (Granger and Hayne 2001). With this in mind, we have assigned a notional 50-yr ARI to the 1954 event.

At the southernmost end of the area impacted—the Clarence River catchment—the February 1954 event resulted in a flood level of 7.72 m at Grafton (a town located in the lower part of the catchment downstream of the merging of all three major rivers in the upper catchment—the Clarence, Mann, and Nymboida Rivers), very close to the other four highest flood heights since records were first kept in 1839: 7.88 m (March 1890 flood), 7.83 (January 1887 flood), 7.78 m (June 1950 flood) and 7.73 m (February 1893 flood) (Clarence Valley Council 2012). We have again notionally assigned an ARI of 50 years to the flooding here.

We also considered the 1954 flood event from two other perspectives: rainfall frequency and the return period of TC137. First in respect to rainfall, an analysis similar to V1.1 of the Global Precipitation Climatology Centre (GPCC) VASClimO 50-yr 1° precipitation climatology (Beck et al. 2005) was undertaken for the study domain 28°–31°S, 152°–154°E and shows the February 1954 rainfall to be the highest over the period 1950–2000.

Second, a statistical analysis of the Bureau of Meteorology's (BoM's) tropical cyclone database (http://www.bom.gov.au/cyclone/history/index.shtml) reveals an ARI for a tropical cyclone of the intensity of TC137 crossing the coast near Coolangatta—the proximate cause of the flooding—in excess of 100 years. In fact, TC137 was the strongest cyclone to make landfall south of 26°S in the BoM database. This database goes back to 1907 but central pressure information was not consistently recorded prior to the 1950s.

In summary, we have taken a conservative view of the 1954 event in assuming a notional ARI of 100 years for flooding in the two most impacted catchments (the Tweed River and Richmond River catchments), in line with the view of engineering studies undertaken for the relevant councils and a lower figure of 50 years for the flooding in the Gold Coast region in the north and the Clarence River catchment in the south. While we do not expect all parts of all catchments to flood to a similar level, the wide geographical distribution of impacts has been highlighted already in section 2, as was the synchrony of flooding in adjacent catchments and the high regional rainfall. We acknowledge the uncertainties in these choices but it seems likely that the actual ARI of the flooding was in excess of these, especially in NSW, and so the accompanying loss estimates to follow will likely err on the low side and provide lower-bound values. Importantly we have better data for the most highly impacted catchments.

b. *Exposure: National residential housing portfolio*

A national residential housing portfolio (NRP) was developed for this project. The NRP was developed using the Australian Bureau of Statistics (ABS) 2006 Census of Population and Housing,[2] which has been updated every five years since 1961 and aims to capture the number of people in Australia and key attributes about them and their dwellings. Building value is estimated on a state basis using data from the ABS, including building approval data, average replacement costs, and the average nominal value of new dwellings. The average replacement value of a home in 2006 values in NSW and QLD was

[2] 2011 census data were not available when this study was undertaken.

AU$240 000 and AU$220 000, respectively. The value of home contents was derived from analyses of several insurance company residential portfolios and set at 27% of the average value of a home. The use of these average values is reasonable given that the region is relatively small and fairly comparable in terms of physical and socioeconomic environments, including climate zone, terrain, land cover and use, settlement, and population, and that previous damage as reflected by insurance claims remains stable.

A complication in estimating losses for the GCR arises because a proportion of the buildings are multistoried apartments and thus losses will be lower than implied by the total number of addresses. The Geocoded National Address File (G-NAF; www.psma.com.au) contains multiple addresses for each multistory building and although they are assigned to the same location, many will be above the first floor. In the absence of better information, these addresses have been treated as single, single-story buildings, to approximate the losses as if only ground-level apartments were inundated. Again this is a conservative choice in keeping with our desire for a lower-bound estimation of the risk.

c. *Flood loss estimation*

The first step in estimating the residential flood loss component ML_{2006} is to estimate water depths at the assigned ARIs at individual addresses (Leigh et al. 2010). This is done using "design" flood surfaces arising from hydrological and hydraulic modeling studies undertaken for local councils, digital elevation models, and geocoded addresses (G-NAF). Risk Frontiers' proprietary flood vulnerability functions were then used to convert water depths into fractional losses at each address as a proportion of the total sum insured or home replacement values: these functions were developed from insurance claims information and engineering reports from the 1974 Brisbane, 1998 Katherine, and 2007 Hunter Valley floods and validated for the 2011 Brisbane floods. We multiply these fractional losses by the average cost of a residential home (2006 values) to obtain the residential loss for the modeled domain.

1) Floor heights

Floor heights are a critical determinant of total damage sustained during a flood: insured claims from residential homes are first incurred when flood waters are at ground level, and then increase rapidly once water levels exceed the height of the floor. For our purposes, we adopt an average floor height of 27 cm based on 2006 household survey data for the town of Casino in the major impacted catchment (Richmond Valley Council 2012). This is close to what we would expect for "slab-on-ground" (slab-on-grade) construction, as is now widely employed across Australia. Moreover, and as will be seen in later discussion, it is the Richmond River catchment that contributes the largest proportion of the modeled loss. We also undertake a sensitivity analysis of the modeled loss as a function of this key variable (see later discussion).

TABLE 1. Proportion of G-NAF addresses in each catchment that are located within the modeled domain. The eight catchments comprise the study domain.

Catchment	Proportion (%) of addresses with flood information in the modeled domain to all G-NAF addresses in each catchment
Coomera	24
Nerang	63
Tallebudgera	0
Tweed	85
Brunswick	0
Richmond	25
Clarence	36

2) Modeled domain

The main focus for local councils to date, as reflected in Table 1, has been to map and quantify the flood risk to key urban centers like those in the GCR (Nerang and Tweed) and in the Richmond (Lismore) and Clarence (Grafton) catchments. Table 1 shows the proportion of total addresses in each catchment that are located within the modeled domain and that have flood information available. Nerang and Tweed have complete coverage while the smaller Brunswick and Tallebudgera catchments, which lie outside the modeled domain but still within the study domain, have none. The Brunswick and Tallebudgera catchments account for only 1.6% and 12.4% of the entire study domain in terms of catchment area and number of G-NAF addresses, respectively (Table 3).

d. *Losses outside the modeled domain*

We estimate the loss in areas that fall within the study domain but beyond the modeled domain (Table 1) by the product of the average modeled loss per dwelling ($\overline{x}$) for those dwellings *inside* the modeled domain and the number of *additional* flood-affected addresses (K) outside the modeled domain [Eq. (2)]. A starting point for determining K was the Leigh (2006) estimates of the number, by Local Government Area (LGA), of residential homes prone to *over-ground* flooding from an ARI 100-yr flood. (This ground level flooding is to be distinguished from overfloor flooding where the home interior becomes inundated). These data were supplemented by detailed examination of flood extent maps,

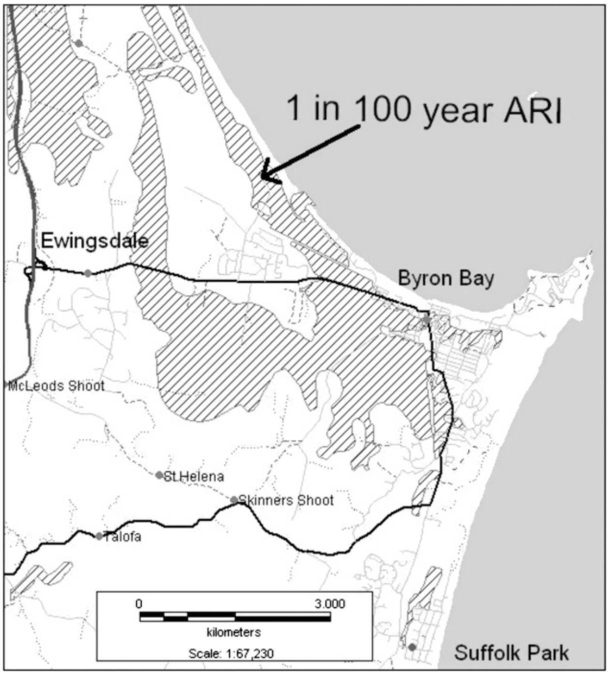

FIG. 4. Digitized 100-yr ARI flood extent of Byron Bay, Suffolk Park, and Ewingsdale (Source: Byron Shire Council 2000). The number of flooded addresses within the 100-yr ARI flood (striped area) is determined by overlaying this map with the G-NAF address file. The bold black lines represent major roads.

flood inundation guides, and engineering reports sourced from local councils, NSW government agencies, and the State Library of NSW.

To refine the Leigh (2006) estimates, flood extent maps and inundation guides were digitized and geographically referenced. By using geocoded address information we are able to estimate the number of addresses that lie within the 100-yr ARI for locations in Tweed River and Richmond River catchments and the 50-yr ARI for locations in the Gold Coast region and Clarence River catchment. Figure 4 shows an example for the Byron Bay, Suffolk Park, and Ewingsdale areas.

e. *Normalization adjustment*

The NRP described in section 3b that was used to calculate ML_{2006} and AL_{2006} [Eq. (1)] is based on 2006 data, the most recent available. To convert these losses L to 2011 societal conditions (ML_{2011}, AL_{2011}), we employ the methodology of Crompton and McAneney (2008):

$$\begin{aligned} L_{M2011} &= n \times L_{M2006} \\ &= n_{GCR} \times L_{M2006,GCR} + n_{NRR} \times L_{M2006,NRR}, \end{aligned} \quad (3)$$

where n [in Eq. (1)] = $N \times D$, N is a ratio of the number of dwellings in 2011 (from extrapolating the 2001 and 2006 ABS census data) to those in 2006, and D is a ratio of the state specific average nominal value of new dwellings in 2011 to 2006. The GCR is in Queensland and the NRR is in New South Wales.

f. *Other lines of business—Commercial and industrial losses*

Our approach thus far only accounts for damage to residential buildings and so these estimates must be scaled up to account for losses from other lines of business (OLB), such as commercial and industrial property. These losses can be significant in floods in Australia as many commercial and industrial areas are often located on floodplains.

Since 1967, the Insurance Council of Australia (ICA) has maintained a list of insured losses from natural disasters (Crompton and McAneney 2008). For some events, losses to residential and OLB are available and we use the riverine and flash flooding entries in this data (shown in Table 2) to determine R [Eq. (1)]. For events with larger losses (the top four records in Table 2), the ratio (OLB:Res) seems more consistent, but always exceeds 1 (on average, 1.4); for events with smaller losses, the ratio displays wide volatility. This dispersion is easily explained because the smaller losses are likely to be associated with localized flooding and thus reflect

TABLE 2. Residential (Res) and other lines of business (OLB) insured losses for some Australian riverine and flash flood events (Source: K. Sullivan, ICA).

Location impacted	State	Year	OLB (AU$ million)	Res (AU$ million)	Ratio (OLB:Res)
Katherine	Northern Territory	1998	41.4	28.1	1.5
Townsville	QLD	1998	40.2	30.0	1.3
Wollongong	NSW	1998	24.9	14.3	1.7
South East	QLD	2005	28.8	25.1	1.1
North East	NSW	2005	6.9	18.2	0.4
Broken Hill	NSW	2005	1.1	2.8	0.4
Central West	NSW	2005	2.6	0.7	3.7
Total			145.9	119.2	1.2

TABLE 3. Estimated insured losses (AU$, in millions) from an event with similar attributes to TC137 occurring in 2011.

	Catchment	Area (km^2)	No. of G-NAF addresses	Residential losses: Modeled domain (ML_{2011})	Residential losses: Outside modeled domain (AL_{2011})	OLB	Total insured loss (TIL)
GCR	Coomera	490	84 709	51	—	51	101
	Nerang	509	172 424	138	—	138	275
	Tallebudgera	159	42 080	—	79	79	158
NRR	Tweed	1080	38 427	334	10	344	687
	Brunswick	510	20 688	—	142	142	285
	Richmond	7040	64 739	384	377	761	1522
	Clarence	22 310	30 992	252	—	252	503
	Totals	35 560	505 608	1158	608	1766	3532

damage to a limited category of construction types that may not be typical of the entire community. On the other hand, major flooding events such as the 1954 flood will be associated with widespread inundation and damage to a whole range of exposure types (e.g., residential, commercial, and industrial). Despite the paucity of the data available, we assume that losses to OLB are *grosso modo* equal to those for residential home and contents (i.e., we set $R = 2$). Again, this is a conservative choice.

4. Results and discussion

Our estimate of the average insured loss per homeowner for those dwellings inside the modeled domain ($\overline{x}$) was AU$30 000 for 2006 and AU$41 800 (when normalized to 2011 values [Eqs. (1) and (2)]. This figure is in close accord with the average residential insured loss observed in the 2010/11 Queensland floods of $40 555 (ICA 2012a) across the state. Our use of the mean value here for homes that are impacted but located outside of areas covered by flood mapping is reasonable given that the number of homes affected (K) is large and the fact that the uncertainty in the mean loss reduces as $1/\sqrt{K}$ by virtue of the law of large numbers (Vose 1996). (A similar argument can be made to justify use of the mean vulnerability curves.)

Table 3 shows both the breakdown by catchment and the total for our best estimates of the total insured losses [Eqs. (1)–(3)] if an event similar to TC137 had recurred in 2011. The total insured loss for the event is estimated at AU$3.5 billion with approximately 43% of this loss stemming from one catchment, the Richmond. There are two main reasons for this: first, the Richmond catchment is physically large compared with most of the others, and second, it contains the highest single concentration of addresses at risk in the town of Lismore (Fig. 3). The availability of high-quality flood mapping in this catchment means that we have high confidence in this component of the modeled loss.

The three GCR catchments contribute 59% of the total number of addresses in the study domain but account for only 14% of the TIL. This means that our modeled insurance loss for the event scenario is relatively insensitive to the assumptions made in respect to the ARI assigned to the flooding in these catchments. Had landfall occurred farther north, however, and followed a similar southward track to TC137, then we would expect significantly higher losses across the GCR.

Our TIL estimate of AU$3.5 billion can be compared with other significant weather-related insured losses contained in the ICA Disaster List that were normalized by Crompton and McAneney (2008) and recently updated by Crompton (2011). Table 4 suggests that a recurrence of TC137 would rank third on the list of insured losses since 1967 behind the Sydney hailstorm and Tropical Cyclone Tracy. The loss would be above both other floods in the top 10, the Brisbane flood of 1974 and the 2010/11 Queensland floods. This high ranking can be directly attributed to the growth in dwelling numbers and values illustrated in Figs. 1a and 1b, the large area of the catchments and number of settlement areas affected, and the assumption of complete insurance penetration as discussed above. Once again we note that still larger losses would be possible had TC137 made landfall farther north.

A first-order estimate of the normalized economic loss can also be made by adjusting our estimated AU$19 million loss in 1954 values for changes in nominal GDP per capita and population in the most affected locations. When calculating the GDP factor, we extrapolated GDP back from 1960 to 1954 using the average growth rate from 1960 to 1970. The population factor was calculated by averaging the factor increase in population of the most-affected local government areas. All data were sourced from the ABS. In 2011 values, the normalized economic loss is approximately AU$7.6 billion.

By way of comparison, we note that the ratio between total economic and insured losses in the 2010/11

TABLE 4. The TC137 TIL in 2011 values (in bold) relative to the nine other highest normalized insured weather-related losses (2011AU$, in millions) (modified from Crompton 2011).

Rank	Event	Year	Location	State	Loss (AU$ million)	Normalized loss (2011) (AU$ million)
1	Hailstorm	1999	Sydney	NSW	1700	4296
2	TC Tracy	1974	Darwin	NT	200	4090
3	**TC137**	**1954**	**GCR/NRR**	**QLD/NSW**	**N/A**	**3532**
4	Flood***	1974	Brisbane	QLD	68	2645
5	Flood**	2010/11	Multiple	QLD	2400	2529
6	Hailstorm	1985	Brisbane	QLD	180	2063
7	Ash Wednesday bushfires**	1983	Multiple	VIC/SA	176	1796
8	Severe storm	2007	Multiple	NSW	1480	1742
9	TC Madge	1973	Multiple	QLD/NT/WA	30	1492
10	TC Yasi	2011	Multiple	QLD	1300	1352

* The 1974 Brisbane flood resulted from the degeneration of Tropical Cyclone Wanda.
** Note that the insurance penetration in these floods is unknown but would have been less than the 100% assumed for TC137.

Queensland floods was approximately 3 (Swiss Re 2012; Munich Re 2012). Given that riverine flood was not uniformly insured in 2011—as has been assumed here—and that the AU$19 million loss in 1954 is a lower-bound estimate, a figure of AU$7.6 billion, roughly twice the estimated total insured loss (AU$3.5 billion), seems reasonable. It was beyond the scope of this research to investigate the broader economic impacts of this event.

5. Modeling limitations

In our deterministic flood loss estimation methodology, a series of rationales along with observed and modeled data have been provided to justify our estimated TIL as a lower-bound figure. Like any modeling exercise, however, our approach has limitations. We have dealt with the choice of some key inputs such as the ARI of the flooding in the various catchments, the distribution of exposure, and adjustments necessary to include losses outside of the areas covered with flood maps. A very conservative estimate of equality ($R = 2$) was adopted for OLB and residential losses: given the large proportion of area zoned for agriculture and commercial and industrial activities in the Tweed, Brunswick, Richmond, and Clarence catchments, losses from OLB will be significant and accounting for these as a rough multiple of residential losses is crude, although justified here given the absence of better information.

The choice of 100-yr ARI for the 1954 flooding on most affected river catchments is reasonable and in line with the modeling used for land-use planning by the principal local government areas affected. The use of the average modeled loss per address for those areas beyond the modeled zones is perhaps harder to justify except on the grounds of plausibility and the fact that the average of $41 800 is in close accord with that experienced in the recent 2011 Brisbane floods and is in the region next to the study area.

We have not explicitly considered any improvements that have been made to existing flood defenses in several locations. The reason for this is that the councils themselves state that these are designed to provide protection only for a 1-in-10-yr event (e.g., Richmond River County Council 2012) and thus we would expect them to fail or be overtopped in a 100-yr ARI flood.

Additional losses due to flash flooding from minor rivers and streams and storm surge have also not been explicitly accounted for. These can only add to our estimate of TIL and our neglect of them, except in the sense that they are loosely embraced within losses from the OLB, contributes toward our belief that our estimate of the TIL is a lower-bound estimate. Importantly, those catchments contributing most to this loss have been well accounted for.

No allowance was made for construction improvements in tropical cyclone–prone areas of the country (Crompton and McAneney 2008) as wind was only a minor contributor to the original 1954 loss and would be expected to be even lower today because of improved construction standards (Mason et al. 2013).

Finally we have assumed an insurance penetration of 100%. We remind the reader that the adoption of insurance for residential properties in Australia is close to 100% and that coverage for other natural hazards is automatically included in standard homeowners policies. Flood has been the exception but since the 2011 Queensland and Victorian floods the government is aggressively pushing the insurance sector to include cover for riverine flood as a standard inclusion. As of November 2012 nearly 80% of household policies sold in Australia already contain flood insurance (ICA 2012b).

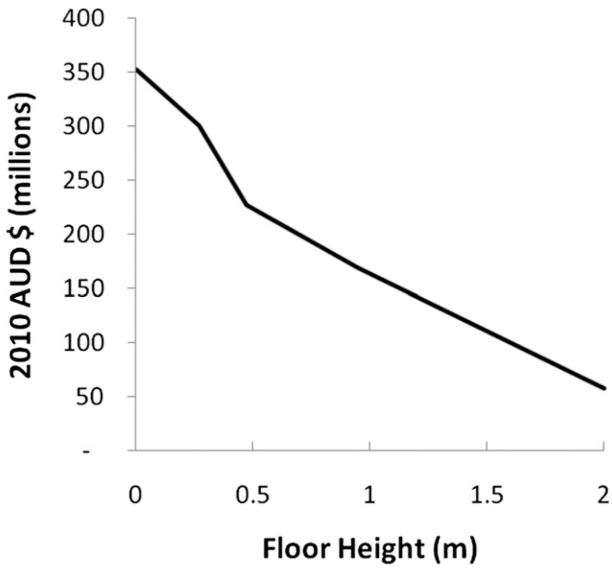

FIG. 5. The loss sensitivity in the Tweed River catchment to changes in residential floor heights.

6. Policy implications

Our study has shown a likely lower bound of $3.5 billion in total insured losses if a flood with similar attributes to the 1954 flood were to recur in 2011 and this would rank as the third most costly weather-related normalized insured loss in Australia on record. The collective evidence presented here emphasizes the contribution of increasing property numbers and the value of these assets on floodplains as the primary reason for this high value.

Better construction standards, particularly elevated floor heights, would help to offset losses. Unfortunately many modern buildings are now built as ''slab-on-ground'' construction and have floor levels much lower (~27 cm) than the traditional ''Queenslander'' style with elevated floor levels (1–2 m). Figure 5 shows the resulting of rerunning the modeling for a range of possible average floor heights in the Tweed River catchment and highlights the loss-reducing potential of raising floor heights. This could be applied to new construction where, for whatever reason, building on the floodplain is unavoidable.

In terms of the loss outcome, a reduction in floor height has the same effect as increasing the ARI of flood depths and vice versa. Thus Fig. 5, which is designed to address the sensitivity of modeled losses to floor height, also serves as a sensitivity analysis for uncertainty in flood level for a given floor height. It is clear that the uncertainty in modeled flood levels of, say, 10 to 20 cm, and hence the exact choice of the ARI of the extent of flooding, has a relatively minor impact on the modeled loss compared with the impact of raising or lowering floor height a meter or so. However, in our view, the analysis best serves as a warning against the uninhibited expansion of development on floodplains and particularly the widespread use of ''slab-on-grade'' construction.

The 2010/11 Queensland floods also highlighted the critical role that land-use planning can play in amplifying disaster losses. The footprint of the Brisbane 2010/11 floods was almost identical to that of the 1974 Brisbane flood (van den Honert and McAneney 2011). If the GCR and NRR grow as forecast, the need for risk-informed planning policies will become ever more pressing (Roche et al. 2010). Homeowners often choose not to implement mitigation measures because they either underestimate the risks or do not learn from history (Kunreuther et al. 2009). The situation is aggravated for flood in Australia since many modern materials widely used in home construction and built-in joinery do not support immersion (New South Wales Government 2006).

Last, our Australian case study highlights issues that are by no means restricted to flooding risks. For example, Crompton et al. (2010) have highlighted the growth in exposure in close proximity to Australian bushlands and the inevitability of property losses occasioned by the 2009 Black Saturday bushfires in Victoria. In the authors' view, prudent land-use planning and construction standards are needed if disaster losses are to be minimized. And as has been illustrated in the 2011 Brisbane floods, it is incumbent upon authorities to take an even more conservative approach where there are large populations at risk (Walker and Musulin 2010). This is not only justifiable on grounds of life safety, but large-scale disasters can significantly impact the national economy and attract a higher cost of risk transfer for insurance.

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