

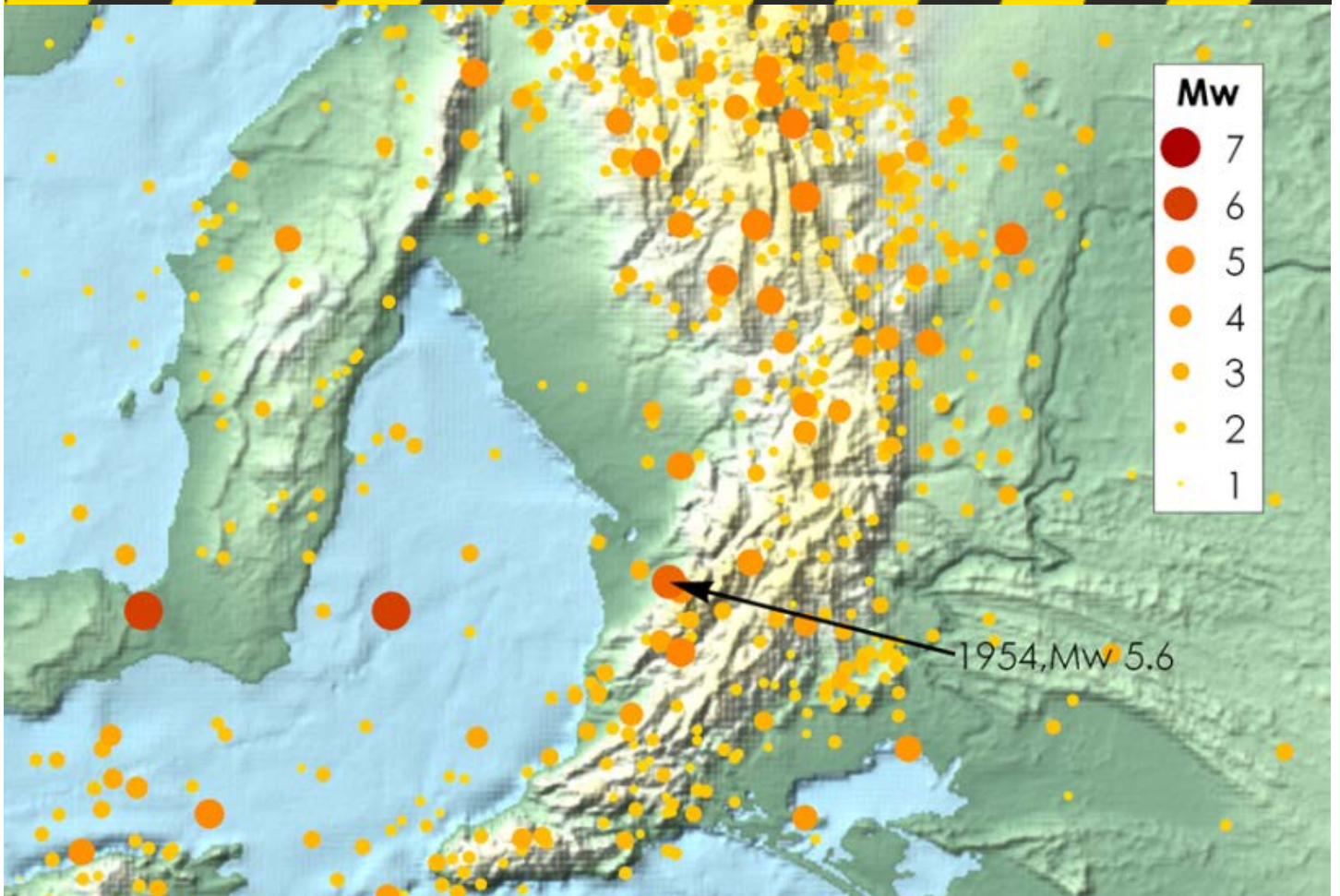


AN EARTHQUAKE LOSS SCENARIO FOR ADELAIDE

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Cover: A map of where earthquakes have occurred in south east South Australia.

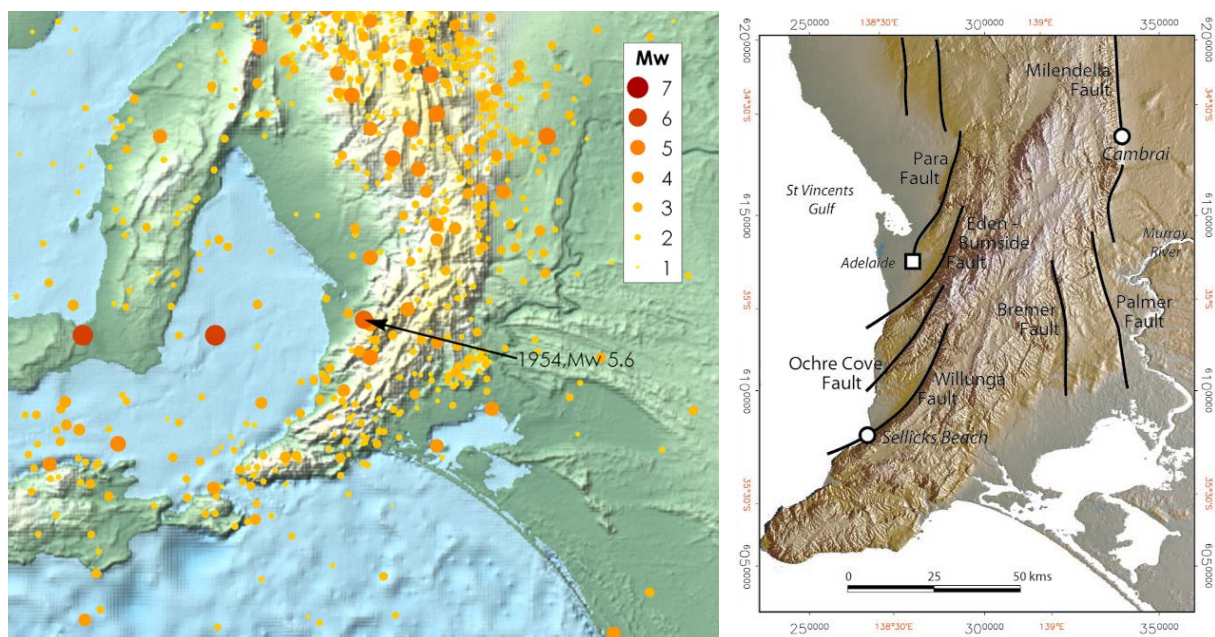


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INTRODUCTION

Despite its low seismic activity, Australia is more vulnerable to earthquakes than one would expect due to the concentration of population and the large stock of buildings which are structurally unable to withstand even moderate seismic shaking. This was demonstrated by the 1989 M5.6 Newcastle earthquake, one of the costliest natural disasters in Australia, despite its low magnitude. One question elicited by these circumstances is: what would happen if one of Australia's main cities were hit by an earthquake similar to the Newcastle earthquake? An example of a near miss is the 1954 M5.6 Adelaide earthquake, whose epicentre, far from developed areas at the time, would lie in densely developed areas were it to occur today. Providing realistic estimates for natural disaster scenarios is essential for emergency managers. A systematic approach to developing such scenarios can reveal blind spots and vulnerabilities in planning.



(a) Historically recorded earthquakes (1840- present), source Geoscience Australia.

(b) Active faults, from Sandiford [2003]

Figure 1: Scenario's selection information.

The Adelaide region is undergoing active tectonic deformation caused by earthquakes occurring on a system of prominent active thrust faults that are oriented approximately north-south and are uplifting the Mount Lofty and Flinders Ranges. The earthquakes are caused by high horizontal compressional stresses oriented in the east-west direction. The largest historical earthquake to have occurred in Adelaide is the March 1, 1954 Mw 5.6 earthquake, which is thought to have occurred on the Eden-Burnside fault that lies just east of Adelaide (Figure 1a). The Para fault is located directly beneath the Adelaide CBD (Figure 1b). The largest earthquakes that can occur on these faults have magnitudes that are thought to lie in the range of 7.0 to 7.5, but earthquakes that large would have notional recurrence intervals of tens of thousands of years [Clark and McPherson, 2011]. Earthquakes as large as magnitude 6 are estimated to have recurrence intervals of about 1,000 years. Earthquakes with return intervals of 500 years, which form the basis of the seismic provisions for the building code [Standards Australia, 2007], have magnitudes of about 5.5. Smaller earthquakes also occur in a distributed manner throughout the region, not only on the identified



active faults. Figure 1a shows the epicentres of the historically recorded earthquakes in the Adelaide region from 1840 until present days.

The event we consider is a M6 occurring on the Para Fault, with an epicentre about 7 km from Adelaide CBD, generating peak ground accelerations in the range 0.3 – 0.4 times the acceleration of gravity (0.3g-0.4g) in the CBD. Figure 2 shows the location of the epicentre.

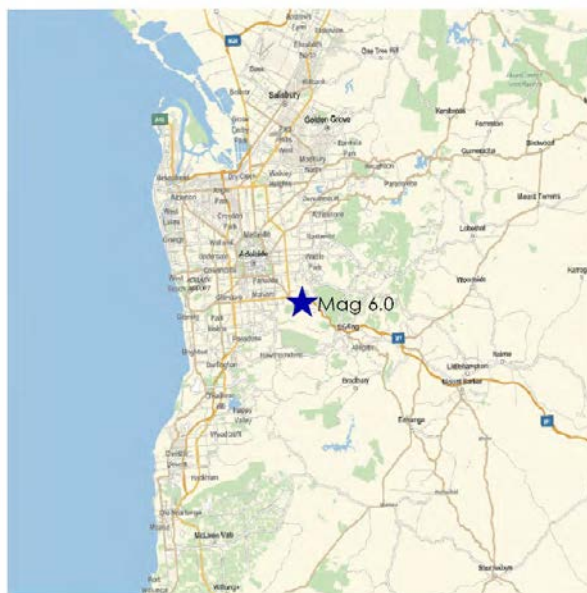


Figure 2: Epicentre location.

METHODOLOGY

We estimate the probable ground motion level for the chosen event using the ground motion prediction equations developed by Somerville et al. [2013] and the soil condition maps from McPherson and Hall [2006].

The calculation of losses is performed with the methodology developed by the US Federal Emergency Management Agency (FEMA) through its model HAZUS [FEMA, 2004]. The HAZUS methodology provides functional relationships between physical earthquake parameters and probability distribution of building or infrastructure response to shaking and therefore damage. The HAZUS methodology also provides estimates of the number of casualties. These estimates take into consideration the probability that a structure will collapse, the spatial distribution of people at different times of the day, and the likelihood of a person being indoors or outdoors at the time of the earthquake.

The methodology provided by HAZUS entails a high degree of uncertainty since many factors determining the outcome of an earthquake cannot be modelled a priori. For example, the time of day plays an important role in determining human casualties: the 2007 Gisborne earthquake hit at 8:55pm resulting in no direct casualties, despite many parapets falling in footpaths across the town (see section 2 of AEE [2008]).

To estimate the damage (material, financial and casualties) caused by the earthquake we use the exposure datasets summarised in table 1.



Table 1: Datasets used in the modelling.

Population Distribution	We perform an analysis of the 2011 Census and statistics provided by the Department of Higher Education . We estimate the population distribution at two different times of a mid-week day, 2.00 AM (Night time scenario) and 2.00 PM (Day time scenario). These scenarios are expected to generate the highest casualties for the population at home and the population at work/school, respectively. Figure 4 shows the estimated population density during the day and at night time.
General Building Stock	From the National Exposure Information System (NEXIS) database, aggregated at the SA2 level, and the Geocoded National Address File (G-NAF) database. Figure 3 shows the G-NAF addresses locations, the black dots, and the SA2 areas on which the NEXIS information is available, the coloured polygons.
Critical Infrastructure Inventory	From the RoadNet (Map Data Services) and Features of Interest (PSMA) databases.

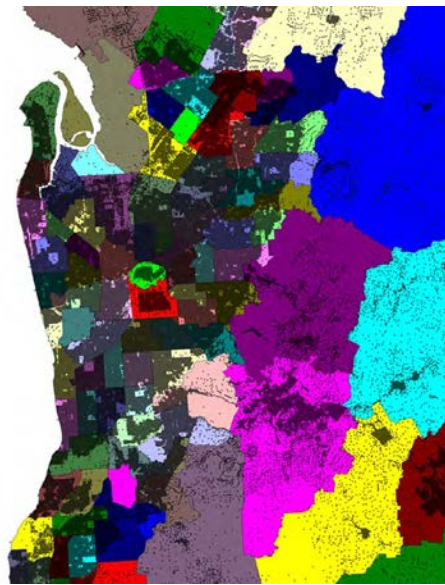
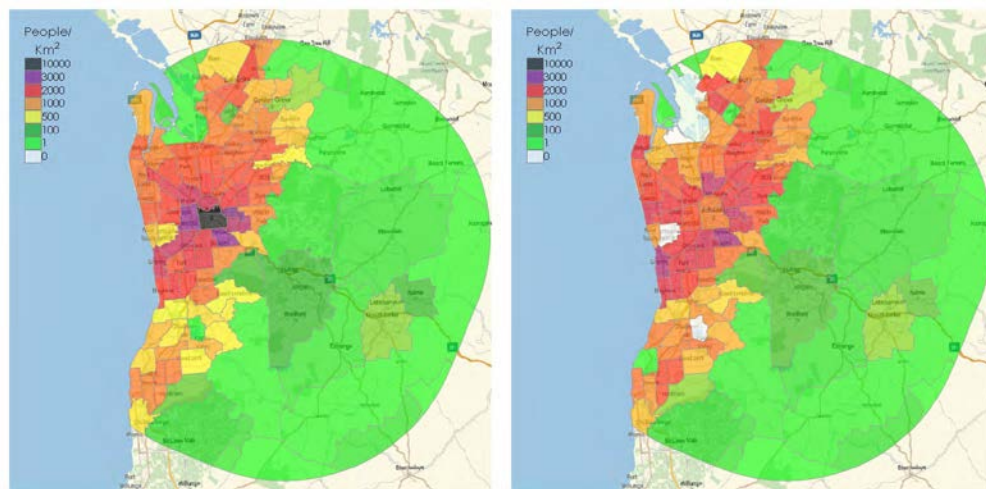


Figure 3: Buildings exposure data. Black dots: G-NAF addresses. Coloured polygons: SA2 areas.



(A) Day Time.

(B) Night Time

Figure 4: Population Density within 25km from the epicentre



HAZARD MODELING

We model the event (Figure 2) as a rupturing fault plane. The top centre of the fault plane is placed 7 km ESE of the surface trace of the Para fault at a depth of 7 km on a 45 degrees fault dipping at 45 degrees to the ESE. Fault dimensions are consistent with Leonard [2010] and Somerville et al. [2013].

GROUND SHAKING

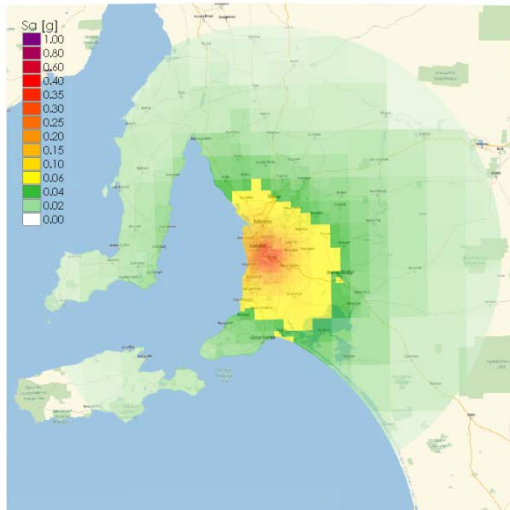
The probable (median) ground motion level for the chosen event is calculated using the ground motion prediction equations developed by Somerville et al. [2013] and the soil condition maps from McPherson and Hall [2006]. We calculate the full demand spectrum for each location.

Figure 5 shows spectral acceleration at all the affected locations for a range of periods.

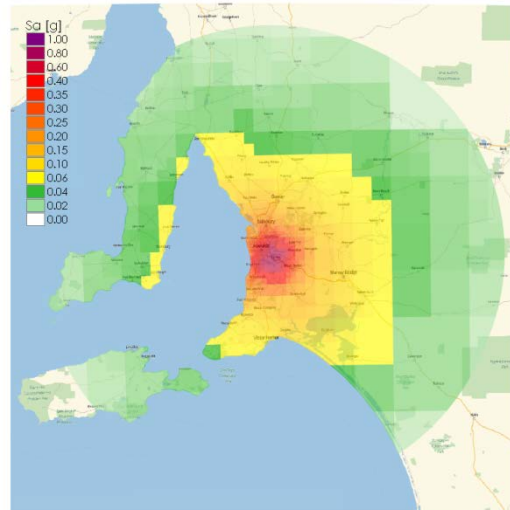
GROUND DISPLACEMENT

The likelihood of experiencing ground displacement due to liquefaction at a specific location is primarily influenced by soil type, ground shaking intensity and duration, and depth of groundwater.

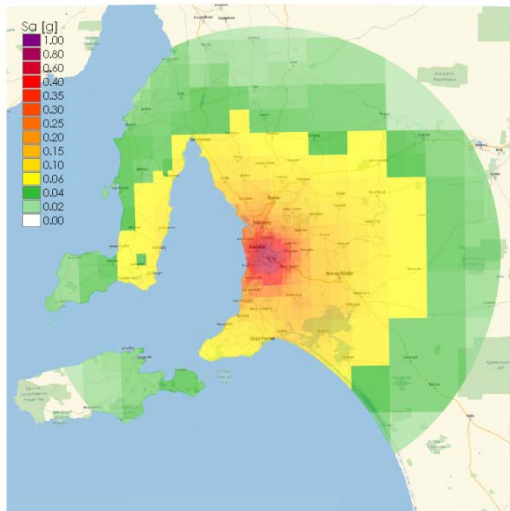
Liquefaction damage was one of the main causes of destruction in the Christchurch 2010 event, affecting transportation and water networks. We have produced a liquefaction potential map for Adelaide by using a statistical model that uses distance to water bodies, elevation, soil type and ground shaking to parameterize the probability that a site will liquefy, [Knudsen et al., 2009]. For this scenario, liquefaction would likely occur around the banks of the Torrens river and of the creeks on the south-east of the CBD, and could potentially destroy a number of bridges. Combined with shaking, liquefaction damage may render parts of Adelaide inaccessible for large extents of time and cause long term infrastructure damage. Figure 6 shows an overlay of the Adelaide road network and the liquefaction potential map.



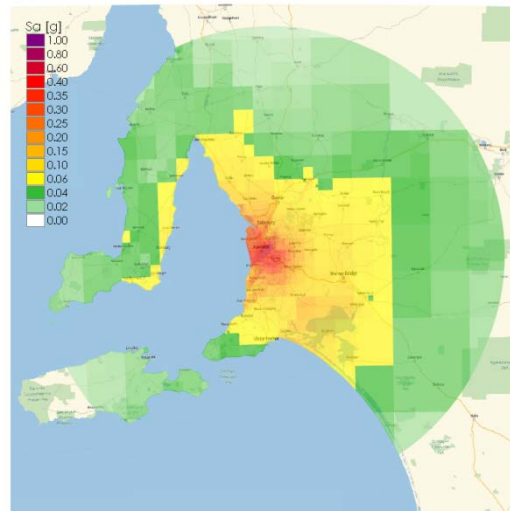
(A) Period = 0.0 sec



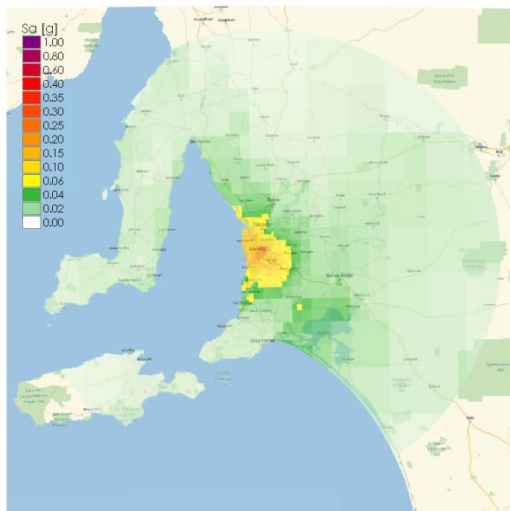
(B) Period = 0.1 sec



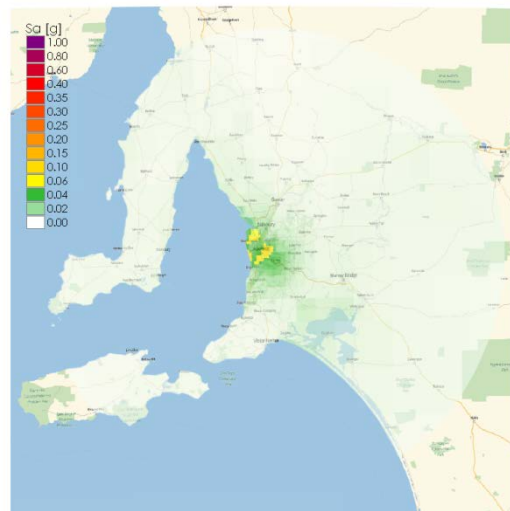
(C) Period = 0.2 sec



(D) Period = 0.5 sec



(E) Period = 1.0 sec



(F) Period = 2.0 sec

Figure 5: spectral acceleration [g] at different periods.

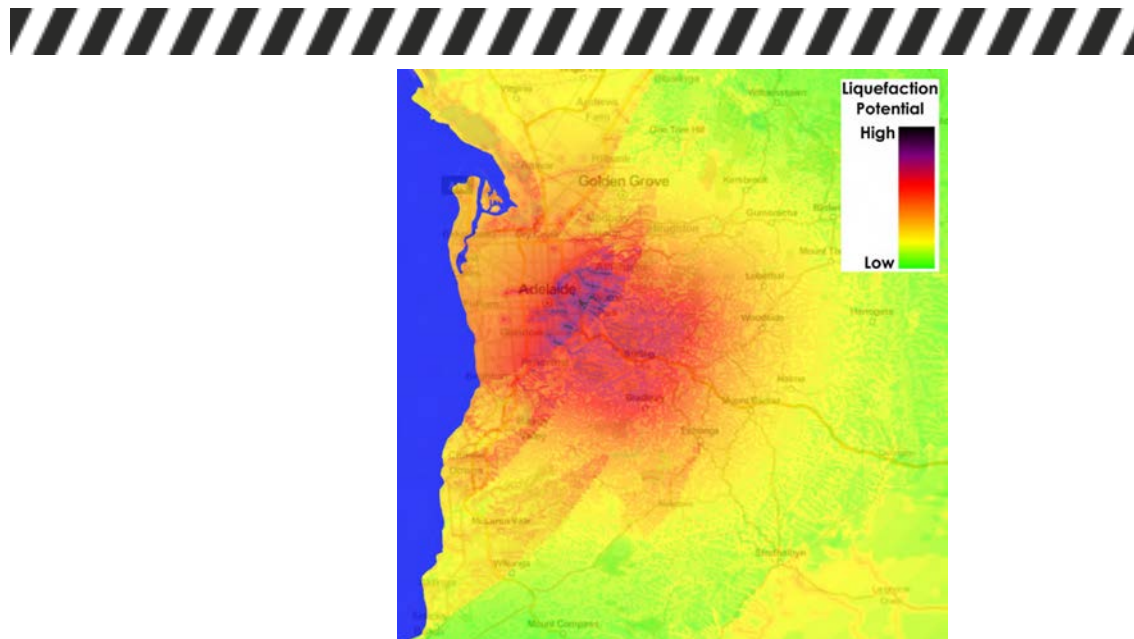


Figure 6: Liquefaction potential map for Adelaide. Hot colours represent areas with higher probability of liquefaction.

IMPACT MODELING

The estimate of the count of casualties and damage to buildings and infrastructure is performed following the HAZUS methodology, FEMA [2004]. It should be kept in mind that HAZUS results are subject to a high degree of uncertainty because of the large number of factors that cannot be modelled. Moreover, HAZUS does not take into account related costs, such as labour and demand surge, nor takes into consideration the inter-relationships between different infrastructures.

To create a realistic scenario, therefore, it is desirable to make also use of information from events that occurred in areas of similar demography, construction practices and cultural background. The modelled results are therefore compared and integrated with observation from recent similar events.

Australia has low seismic activity so our historical experience is limited. Christchurch (New Zealand) on the other hand, has recently been devastated by a series of earthquakes. Given the similarities between New Zealand and Australia, we can use observations from damage assessment field work done following the Christchurch event to hypothesize a realistic scenario for the Adelaide region. This experience also allows us to draw important conclusions, in particular for impacts not covered by models, such as damage to infrastructure, social impacts, unforeseen consequences and long term impacts. It should be kept in mind that the transferability from the Christchurch experience to a possible earthquake scenario in Adelaide is limited to the older Christchurch structures that have not been seismically retrofitted.

We also use the experience obtained from the 1989 Newcastle earthquake, which is third most expensive natural disaster in Australia, in terms of insured losses when normalised to current societal conditions, [Crompton, 2011].

The earthquake that hit Adelaide in 1954 occurred in the vicinity of the chosen scenario event. There is however little information we can gather from it as the available records of the sustained damage is limited and the socio-economic condition as well as the physical extent of the urban area have changed dramatically in the last 60 years.



BUILDING DAMAGE

The demand spectrum earlier described is applied, via the capacity spectrum method described in HAZUS, FEMA [2004], to each building category present in the location according to NEXIS. This allows the evaluation of the structural response of every particular building to each particular demand spectrum. We then use the vulnerability curves provided by HAZUS which best match the NEXIS building categories to estimate the probable damage to the buildings. Figures 7 and 8 show the extent of the damage to residential addresses. Table 2 summarise the Number of Equivalent Addresses Destroyed (Count of Replacement Values) for the whole area.

Table 2: Number of equivalent addresses destroyed.

Line of Business	Number of Addresses
Residential	88,440
Commercial	4,815
Industrial	1,650

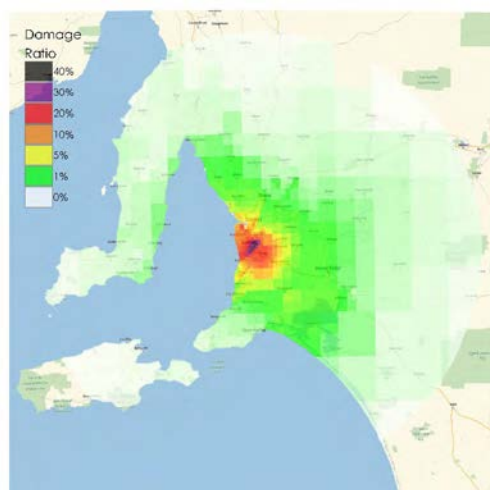


Figure 7: Residential Damage: Percentage of Replacement Value of the local Buildings' Stock.

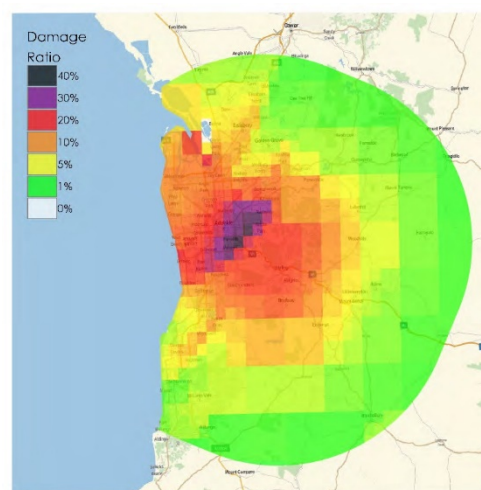


Figure 8: Residential Damage: Percentage of Replacement Value of the local Buildings' Stock. Within 30km of the Epicentre.

CASUALTIES

The damage states probabilities for the building stock are used in conjunction with the estimated population distribution to calculate casualties. The output from the HAZUS model is given on a four level injury severity scale, table 3.

**Table 3:** Injury severity scale

Severity	Description
1	Injuries requiring basic medical aid that could be administered by para-professionals. Injuries that could be self-treated are not considered.
2	Injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status.
3	Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously.
4	Instantaneously killed or mortally injured.

Figure 9 shows the median spatial distribution of severe injuries and deaths (sum of severity 3 and 4) to be expected from the modelled event while table 4 summarises the total counts for all the severity levels.

Table 4: Median total casualties by severity level and time of the day (Number of People).

Severity	Day	Night
1	4,988	5,324
2	1,532	1,650
3	170	167
4	322	327

ESSENTIAL FACILITIES

Essential facilities comprise hospitals, fire and police stations, emergency operation centres and schools – all are essential to provide support in the event of an earthquake (schools provide evacuation centres). Such buildings are designed to withstand higher levels of shaking than ordinary buildings.

It is expected that hospitals should continue to operate even in the event of failures in the power and water networks. Using the appropriate HAZUS methodology, we have estimated a loss of capacity in the area near the epicentre of up to 22%, and up to 14% in the area encompassing the Adelaide CBD, which includes the Royal Adelaide Hospital. Figure 10 maps the loss of capacity overlaid with hospitals, police, fire and SES stations, and ambulance centres. It is estimated that the 7 hospitals nearest to the fault will experience a damage of 20% and around 80 will experience damage on the order of 5%. Some hospitals may have to interrupt their functioning for safety reasons; others may sustain extensive or even complete damage.

Schools are expected to experience similar rates of damage as hospitals, but these facilities are likely to lack the capacity to generate their own power; thus we expect that only those far from the epicentre will be usable as temporary shelter. In Table 5 we show the number of facilities expected to experience sufficient damage to hinder their operations (i.e. > 10%).

**Table 5:** Number of essential facilities expected to experience damage in excess of 10%

Facility	Number
Hospitals	46
Schools	167
Fire Stations	5
Police Stations	5
SES Stations	1
Ambulance Stations	3

INFRASTRUCTURE

Damage was estimated using ground motion parameters shown in Figure 5a and 5e, where areas referred to as “near the epicentre” correspond approximately to the Red-to-Yellow coloured region in Figure 5a. The methodology does not take into account work or replacement materials shortage and should be seen as an estimate of the amount of work without considering the inter-relationships between downtimes from different infrastructures. Tables 6 to 9 summarise the expected damage from modelling and review of past similar events.

Table 6: Transport Damage

Roads	<ul style="list-style-type: none"> At this level of ground shaking (in the absence of liquefaction) roads are not directly considerably affected Roads may be blocked as a consequence of debris from fallen buildings. Roads may also be shut where there is the potential for surrounding building to fail during aftershocks, even if no debris have yet fallen. As a result, and as observed in Christchurch, areas of the CBD may be cordoned off for a minimum of 7 days following the event.
Bridges and tunnels	<ul style="list-style-type: none"> In the absence of liquefaction, bridges may be closed for a day to a week for inspection and repairs of moderate damage. Near the epicentre, a small number of bridges could experience extensive to complete damage and take a minimum of 150 days to be completely restored. Liquefaction may cause damage to bridges at locations indicated with hot colours in Figure 6.
Trams and trains	<ul style="list-style-type: none"> At this ground shaking level (in the absence of liquefaction) there is no significant proportion of railway lines completely damaged. However, some rail and light rail bridges close to the epicentre may be extensively damaged and take a minimum of 110 days to be repaired. A greater proportion (40%) of railway and tram lines close to the epicentre will experience minor damage, which corresponds to a downtime of 2 to 7 days but may be longer depending on ground rupture patterns. The fuel and maintenance facilities for this infrastructure located in the proximity of the epicentre will mostly suffer minor to moderate damage, which may add 2 to 7 days to the downtime. The fuel and maintenance facilities in the neighbourhood of the epicentre will also have a 40% chance to suffer extensive damage, with associated downtimes of up to 4 months.
Airports	<ul style="list-style-type: none"> Adelaide airport is situated around 10 km from the epicentre of this scenario and is situated on soft soil which is prone to liquefaction. Airports are usually well built and are expected to perform reasonably well. However, as observed in Christchurch, airports are expected to be closed for a short period of time for damage assessment, Giovanazzi et al. [2011].



Table 7: Electricity Damage. The scenario described below is consistent with historical experience in Christchurch (2010), Giovinazzi et al. [2011], and Newcastle (1989), Caldwell [2009].

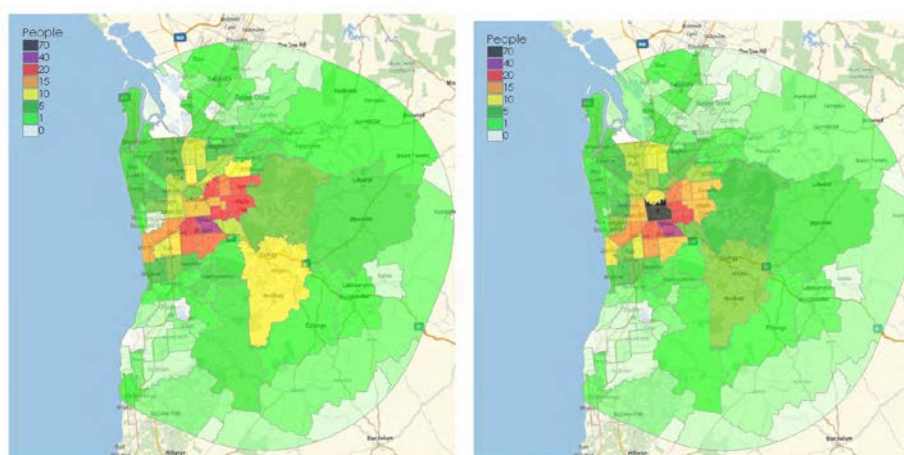
Transformers & Substations	<ul style="list-style-type: none"> The complete failure of large power components, such as transformers or substations, may occur in the proximity of the epicentre with a probability of around 40%, and downtime of approximately two months. According to the HAZUS model, almost all addresses close to the epicentre will experience at least minor power failures with downtimes of up to 3 days (if no nearby substation is completely damaged), see Figure 11.
Power Stations	<ul style="list-style-type: none"> Some power stations, close enough to the epicentre to sustain some slight or moderate damage will take a month or longer to fully recover, see Figure 12.

Table 8: Fresh and Waste water. The modelling results are supported by the experience in Christchurch, Giovinazzi et al. [2011].

Water supply	<ul style="list-style-type: none"> Major water facilities such as pumping stations and reservoirs may experience extensive damage with a probability of 15%, which implies a downtime of 40 days. Minor damage may occur across the network, with a downtime of 3 days (if no major system was completely damaged). In case of liquefaction, breakage of pipes is likely to be widespread in the hot coloured regions in Figure 6, and concerns over contamination may render the water not suitable to drinking.
Waste water	<ul style="list-style-type: none"> Extensive damage is modelled to occur in 25% of wastewater systems near the epicentre even without the occurrence of liquefaction; addresses within this zone may be without sewage services for up to 150 days.

Table 9: Communication Damage. For a description of the Christchurch experience see Fenwick [2011].

Disruption	<ul style="list-style-type: none"> Most of the area near the epicentre will experience minor to moderate damage with downtimes ranging from less than 1 day to a week.
Major facilities	<ul style="list-style-type: none"> About 30% of the major facilities (central offices and broadcast stations) located in the area near the epicentre will experience extensive damage with associated downtimes of up to a month.



(A) Day Time. (B) Night Time.

Figure 9: Severe Injuries and Deaths within 25km from the epicentre.

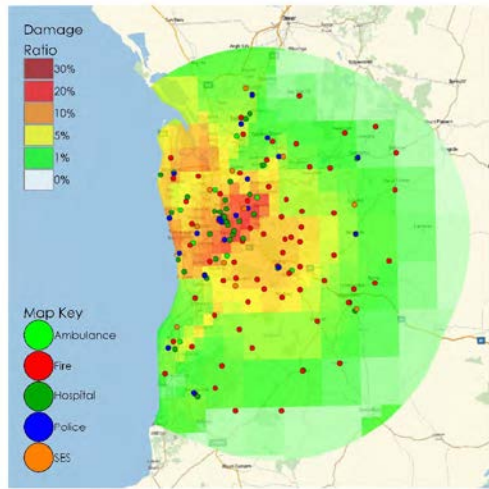


Figure 10: Damage Ratio to essential facilities.

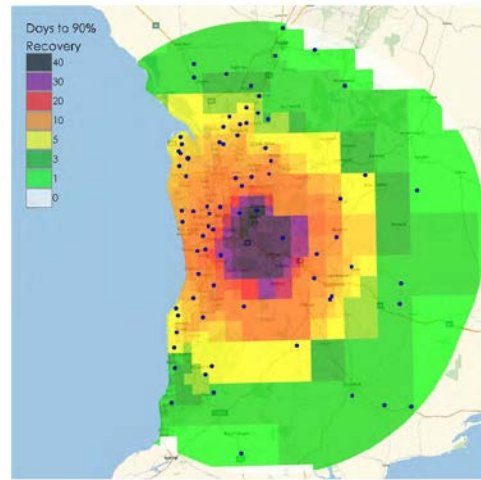


Figure 11: Estimated Number of Days to reach 90% of the Substations' functionality. The Blue Dots indicate the Substations' locations.

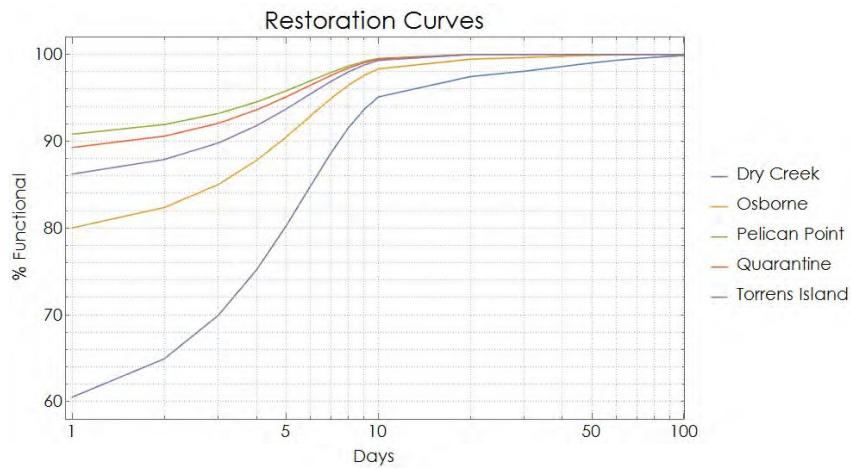


Figure 12: Restoration Curves for some of the power stations near the epicentre.



UNFORSEEN IMPACTS

There are a number of issues that we are not able to model but need to be taken into account when investigating a possible earthquake scenario. Table 10 summarizes the main aspects to consider.

Table 10: Unforeseen Impacts

Chemical and high risk industrial plants	<ul style="list-style-type: none"> • These are usually located away from residential zones. • High risk facilities should be designed for increased resilience to earthquake damage, thus the probability of an accident induced by an earthquake is classified as low. • If, however, there were damage, it would be such as in the 1998 Longford gas explosion in Victoria, Gippsland (Wikipedia [2015b]).
Hazardous material release	<ul style="list-style-type: none"> • Hazardous materials are not exclusive to heavy industry and may be released as a consequence of building collapse. • These may include carcinogenic or corrosive gases, poisonous liquids that contaminate the water table. • Asbestos was used in Australia from the 1950's until 2003 when it was banned and may be exposed as a result of earthquake building damage in an earthquake. • Irrespective of the risk, it will impose large clean-up costs and require the cordoning of many properties.
Fire following earthquake	<ul style="list-style-type: none"> • Fire following earthquake has caused extensive damage in the past (San Francisco, 1906 and Tokyo, 1923). • Extensive fire following earthquake damage is less common in present times, and will likely be localized to high risk sites as was the case for the Cosmo Oil Company fire following the 2011 Tohoku earthquake in Chiba, Japan.
Long series of strong aftershocks	<ul style="list-style-type: none"> • The Christchurch event was notable for its unusual frequency of aftershocks. The most damaging event (M6.3 Lyttelton) occurred as an aftershock of the original event (M7 Darfield) 4 months earlier. • An even more unusual earthquake sequence occurred in Australia: during the period 1883-1892 around 2000 earthquakes occurred off the NE coast of Tasmania (Marion [1987]). • The three largest events, in July 1884, May 1885 and January 1892, had estimated magnitudes of 6.3, 6.6 and 6.9. • The earthquake sequence in Christchurch moved away from the city only one year after the main event, and even its short duration compared with the 1883-1892 Tasmanian sequence has posed a serious challenge to the recovery of the Christchurch CBD. • If an earthquake sequence like the Tasmania sequence occurred near Adelaide it would probably result in a decrease in population and economic importance of the city as businesses migrated to safer areas. The results of such scenario would be devastating for Australia as has been the case for New Zealand.



CONCLUSIONS

Although the earthquake hazard in Australia is low compared to neighbouring countries, the risk to people and build environment is relatively high because of the concentration of population and the large stock of buildings structurally unable to withstand even moderate seismic shaking. The 1989 Newcastle earthquake, ranking as the third most expensive natural disaster in Australia, [Crompton, 2011], being a clear example.

In this report, we present a scenario of potential impacts of a magnitude 6.0 earthquake on the Para fault near Adelaide, SA, with the objective to help emergency managers to:

- visualise potential impacts before disasters happen
- better understand the implications of catastrophic events beyond recent experience, and
- reveal blind spots and vulnerabilities in strategic planning.

The hazard is represented by the response spectrum of a quake at a given location, and provides indication of building response to ground motion; it was simulated using the ground motion prediction equations developed by Somerville et al. [2013] and the soil condition maps from McPherson and Hall [2006]. Expected casualties and impact on buildings, essential facilities and critical infrastructures have been estimated using the HAZUS methodology, FEMA [2004]. We compared and complemented these results with experience from past similar events.

The analysis pictures a potentially devastating scenario for the population and the economy of Adelaide. It should serve as a tool for emergency managers to reason about an event that is beyond the recent experience but has a reasonable possibility to happen in the future and help them plan for such a dreadful occasion.



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