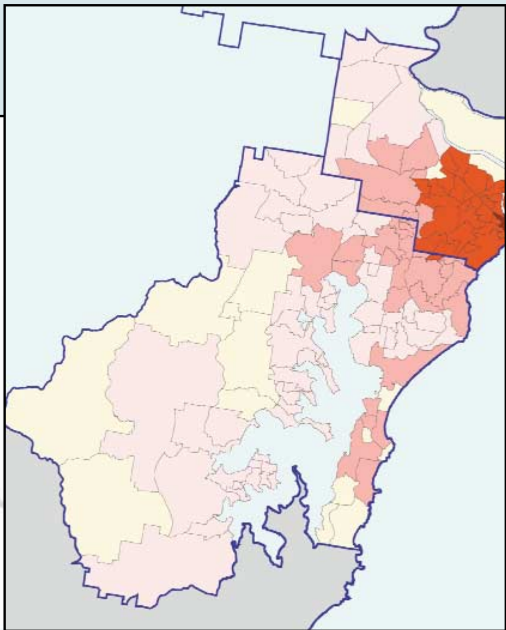
# Earthquake Risk in *Newcastle* & LAKE MACQUARIE



***Edited by Trevor Dhu and Trevor Jones***

GEOSCIENCE AUSTRALIA

**Department of Industry, Tourism and Resources**
Minister for Industry, Tourism and Resources
***The Hon Ian Macfarlane MP***

**Parliamentary Secretary:** The Hon Warren Entsch MP
**Secretary:** Mr Mark Paterson

**Geoscience Australia**
**Chief Executive Officer:** Neil Williams



ISBN: 0 642 46744 7



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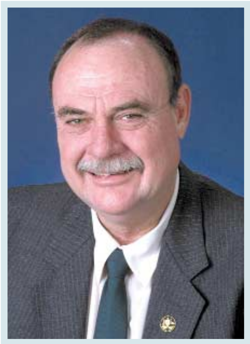
**Key contributors**
Neil Corby, Trevor Dhu, Glenn Fulford, Trevor Jones, David Robinson, John Schneider and Cvetan Sinadinovski

**and in cooperation with**

The City of Newcastle

Hunter Water Corporation,
Hunter District Emergency Management Committee

City of Lake Macquarie



# FOREWORD

Geoscience Australia is Australia's national geoscience research agency. Its Risk Modelling project has taken the leading role in understanding earthquakes and their potential impact upon Australia's urban communities. In Newcastle and Lake Macquarie the potential impact of earthquakes was painfully demonstrated by the 1989 event.

The study of earthquake risk in Newcastle and Lake Macquarie is the product of four years of work. This study builds on work carried out by Geoscience Australia's Cities Project in Cairns, Mackay and South-East Queensland.

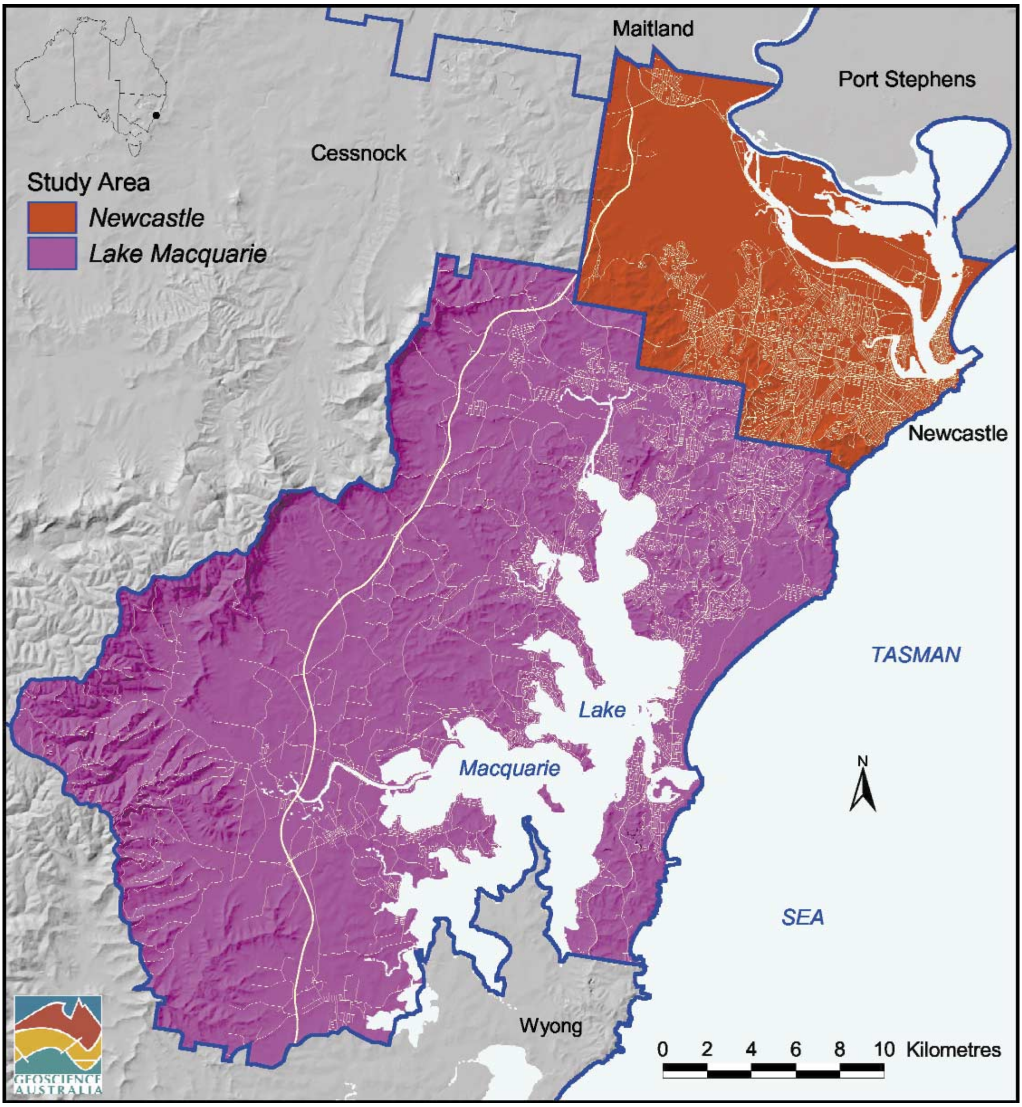
This booklet contains a summary of the risk posed by earthquakes to Newcastle and Lake Macquarie. It includes an overview of the methodology used, and outlines the key results and conclusions. The work has focused on developing and applying models of earthquake hazard, vulnerability and risk that are relevant to Australia's urban communities. A more detailed discussion of the full risk assessment procedure and the associated results are presented in the report, *Earthquake Risk Assessment of Newcastle and Lake Macquarie*, which is presented on the compact disc attached to this booklet.

The results of this risk assessment will be valuable to anyone who is interested in understanding the nature of earthquake risk in Newcastle and Lake Macquarie, especially those involved in mitigating their impact or responding to their effects. This will help in making communities safer and ultimately more sustainable and prosperous. The report will also be of interest to people who wish to better understand the hazard and risk posed by earthquakes.

I urge you to look at the full report on the attached compact disc. This work provides a framework to help us develop communities that are better equipped to deal with this natural hazard. It is important, innovative work and I commend it to you.

**The Hon Warren Entsch MP**
*Parliamentary Secretary to the Minister for Industry, Tourism and Resources*

Parliament House
Canberra ACT 2600


Maitland
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# Background

At 10.27 am on the 28th December 1989 an earthquake measuring 5.6 on the Richter scale shook Newcastle, Australia's sixth most populous city. This moderate-magnitude earthquake claimed 13 lives and caused extensive damage to buildings and other structures. This event clearly demonstrated that moderate-magnitude earthquakes, which frequently occur in Australia, have the potential to dramatically impact Australian communities.

Natural hazards devastate Australian communities almost every year. In response to the danger posed by these natural hazards, Geoscience Australia developed the Cities Project. This initiative began in 1996 and is focused on research to measure and mitigate risks faced by Australian urban communities from a range of natural hazards including earthquakes. The ultimate objective is to improve the safety of communities, and consequently make them more sustainable and prosperous.

# Introduction

In addition to the devastating 1989 Newcastle earthquake, at least four other earthquakes of magnitude 5 or greater have occurred in the surrounding Hunter region since European settlement in 1804. Some of these earthquakes caused damage in areas that, at the time, were sparsely populated. Similar events, were they to occur today in populated areas, would certainly cause significant damage. The frequency with which these events have occurred in the Hunter region suggests that earthquakes pose a genuine threat to the communities there.

This study presents the most comprehensive and advanced earthquake risk assessment undertaken for any Australian city to date. It has focused on the economic losses caused by damage to buildings from earthquake ground shaking, and not on the impacts from other, secondary hazards such as soil liquefaction and surface faulting. The study has adopted a probabilistic approach that makes allowances for the variability that is inherent in natural processes as well as the uncertainty in our knowledge.

The results from this project will assist decision-makers involved in local and state government, policy development, the insurance industry, engineers, architects, and the building and finance industries to manage potential damage and loss of life from earthquakes in Newcastle and Lake Macquarie. The results also have implications for the earthquake risk facing larger Australian cities such as Sydney, Melbourne and Adelaide. This is due to a number of factors, including similarities between the earthquake hazard in Newcastle and Lake Macquarie and other parts of Australia, and similarities between the urban environments, particularly the composition of the building stock.

# Methodology

The general risk assessment philosophy adopted by the Cities Project has been developed from the joint Australia/New Zealand Risk Management Standard, AS/NZS4360-1999. It can be expressed conceptually as follows:

**RISK = Hazard * *Elements at Risk* * Vulnerability of the Elements at Risk**

For the specific case of earthquake risk assessments, this process can be described by the flowchart in Figure 1.

A brief overview of the key assumptions and models used in the Newcastle and Lake Macquarie earthquake risk assessment is provided below. For a detailed description of the adopted methodology, the reader is directed to the attached report.

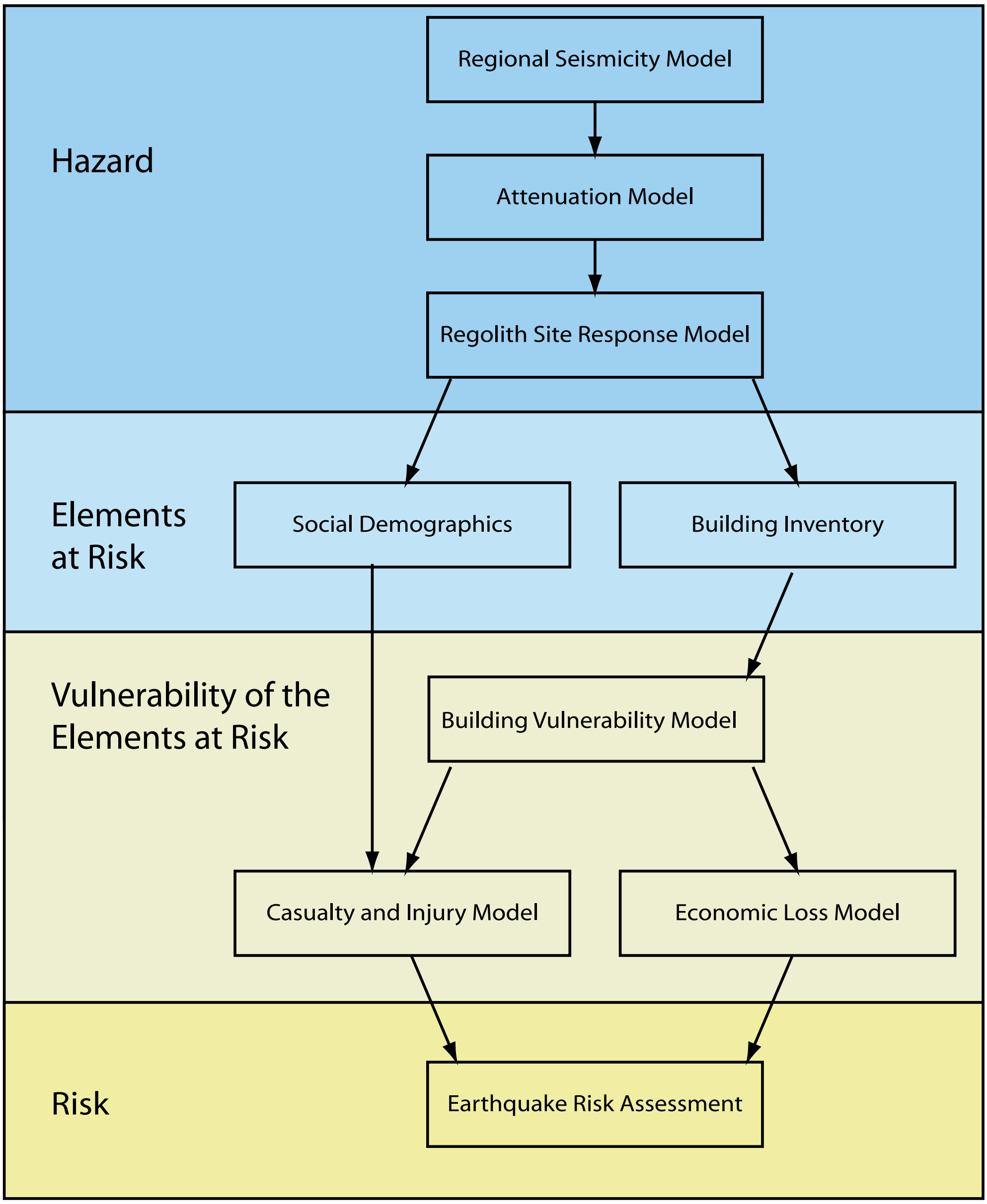


**Figure 1:** Flowchart describing the earthquake risk assessment process as applied to Newcastle and Lake Macquarie

# Earthquake Hazard

The earthquake hazard in a region can be described in terms of the level of ground shaking that has a certain chance of being exceeded in a given amount of time. For example, it is common to describe earthquake hazard in terms of the level of ground shaking that has a 10% chance of being exceeded in 50 years. In order to calculate the earthquake hazard, three key models are needed, specifically:

- a *regional seismicity model*, which describes the chance of an earthquake of a given magnitude occurring in a year;
- an *attenuation model*, which describes generally how earthquake ground shaking or intensity decreases with distance away from the earthquake source, and;
- a *site response model*, which describes how local regolith (soils, geological sediments and weathered rock) will affect the ground shaking experienced during an earthquake.

The *regional seismicity model* was created from historical seismicity and an interpretation of the earthquake occurrence on local geological structures. The model describes the chance of occurrence of earthquakes with moment magnitudes ranging from 4.5 through to 6.5, as these were thought to be the events likely to inflict damage on the study region.

The *attenuation model* of Toro et al. (1997)[1] was used in this study. This attenuation model was developed for central and eastern North America, a region of the world that is thought to have similar attenuation characteristics to Australia. However, it must be emphasised that no explicit study has been conducted on the suitability of this model for Australian conditions.

The site *response model* was developed from detailed geotechnical data which were acquired primarily in the Newcastle municipality, and to a lesser degree the Lake Macquarie municipality. These data were used to classify the study region into six different site classes. State-of-the-art modelling techniques were then used to determine how ground shaking on regolith (soils, geological sediments and weathered rock) would differ from ground shaking on an unweathered rock outcrop.

# Elements at Risk

Geoscience Australia undertook a comprehensive field survey in order to document the characteristics of buildings in the study region that contribute to the building's vulnerability during an earthquake. This survey obtained vital information such as wall construction type and building usage for approximately 6,000 buildings in the study region. In addition to surveying a sample of the general building stock, an effort was made to survey all essential service facilities such as hospitals, and ambulance and fire stations.

# Vulnerability of the Elements at Risk

Earthquake vulnerability models are used to estimate the level of damage caused by a given level of ground shaking for a wide variety of building types. For the purposes of this study, building damage due to earthquake ground shaking was calculated using the method described in Kircher et al (1997)[2]. The vulnerability models were developed specifically for Australian building types. This approach allows the calculation of damage on the basis of building type. For example, given a certain level of ground shaking, the damage to an unreinforced masonry structure would be different from the damage to a timber-framed structure.

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1 Toro, G. R., Abrahamson, N. A. and Schneider, J. F., 1997. Model of strong ground motions from earthquakes in central and eastern North America; best estimates and uncertainties. Seismological Research Letters. 68(1), Pages 41-57.

2 Kircher, C. A., Nassar, A. A., Kustu, O. and Holmes, W. T., 1997. Development of building damage functions for earthquake loss estimation. Earthquake Spectra. 13(4), Pages 663-682.

Models based on work from the Federal Emergency Management Agency (FEMA) in the United States were used to convert estimates of building damage into estimates of economic loss. In this study, economic loss was defined in terms of the restoration cost of local buildings and their contents. The models from FEMA were calibrated using the cost of restoration for local buildings. FEMA models were used to calculate casualty losses in terms of injuries and lives lost.

# **Earthquake** Risk

As mentioned previously, the earthquake risk to the study region is a combination of the earthquake hazard, the elements at risk and the vulnerability of those elements to earthquake ground shaking. In this study, these three components have been combined by:

- conducting computer simulations of approximately 1,200 earthquakes across the study region, each with its own magnitude and probability of occurrence based upon the regional seismicity model;
- using the attenuation and site response models to determine the level of ground shaking from every simulated earthquake at each of the surveyed buildings;
- using the vulnerability models to calculate the damage and economic loss to every building from each earthquake, as well as the related casualties, and;
- aggregating the losses across all the buildings in the study region to produce an estimate of loss for each of the 1,200 simulated earthquakes.

# **Incorporation** of Variability

Any attempt to model natural processes or phenomena should incorporate some of the variability that is inherent in nature. For example, in this work we have classified the entire study region into six different regolith site classes. However, it is unrealistic to believe that every point within a single regolith site class will respond to an earthquake in precisely the same manner. Similarly, it is unrealistic to believe that every timber-framed building in the study area will suffer the same amount of damage given a certain level of ground shaking.

A detailed description of how natural variability has been incorporated into this study can be found within the attached report. However, in essence, the natural variability was incorporated by allowing the model parameters to vary in the simulations. One result of incorporating this variability is that two buildings of the same type, which experience the same level of ground shaking, may suffer different levels of damage. Similarly, the site response and attenuation models were allowed to vary in each earthquake simulation.

# **Verification of the Risk Assessment Methodology –** The 1989 Newcastle Earthquake

A computer simulation of the 1989 Newcastle earthquake was used to test the risk assessment methodology used in this work. The results of the simulated earthquake were compared against records of the actual damage experienced during the 1989 event. For a detailed comparison of the simulated results with those recorded after the event, the reader is directed to the attached main report. When considered on a broad scale, the results of this comparison are very encouraging. For example, the simulated economic loss for the study region in 1989 dollars was of the order of one and a half billion dollars. This simulated economic loss is for both insured and uninsured properties. In comparison, in the aftermath of the 1989 earthquake, the insured losses in 1989 dollars were estimated to be $862 million[3].

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3 Insurance Disaster Response Organisation, 2002, www.idro.com.au.

# **Earthquake Risk** Assessment Results

### Earthquake Hazard in the Newcastle and Lake Macquarie Region

Earthquake hazard is typically measured in terms of the level of ground shaking that has a certain chance of being exceeded in a given time period. The Australian earthquake loading standard, AS1170.4-1993, presents earthquake hazard in terms of an 'acceleration coefficient' that has a 10% chance of being exceeded in 50 years. This acceleration coefficient is considered to be equivalent to peak ground acceleration. A comparison of the earthquake hazard from AS1170.4-1993 with the equivalent hazard calculated in this study is presented in Figure 2. Both maps have the same trend of increasing hazard towards the northeast of the study region. The hazard calculated within this study is typically greater than the hazard suggested by the Australian earthquake loading standard.

The hazard maps presented in Figure 2 were calculated using a peak ground acceleration or similar that would be experienced on a rock outcrop. The damage that is experienced by buildings is often influenced not only by the peak ground acceleration, but also by the level of ground shaking at a specific period of vibration. For example, low- to medium-rise structures are typically more vulnerable to ground shaking that has a period of vibration of approximately 0.3 s than they are to peak ground acceleration. Note also that the buildings in Newcastle and Lake Macquarie are not built on rock, but rather on varying thicknesses of regolith.

Figure 3 presents maps of earthquake hazard for both outcropping rock and regolith, based on the response of idealised low- to medium-rise structures. A comparison of Figure 3 (a) and (b) demonstrates that the regolith, which covers the entire study region, causes a significant increase in the earthquake hazard. Moreover, Figure 3 (b) shows that variations in the regolith material cause significant variations in the hazard across the study region, with areas of deeper regolith generally corresponding to regions of higher hazard.

### Earthquake Risk in the Newcastle and Lake Macquarie Region

The earthquake risk to a region can be described in many ways. However, a common expression is in terms of a risk curve (also called a probable maximum loss or PML curve). A risk curve for the study region is presented in Figure 4. This curve describes the probability of the study region incurring various minimum levels of economic loss within a single year. Economic loss is expressed as a percentage of the total value of all buildings and their contents in the study region. For example, the Newcastle 1989 event had a simulated loss on the order of 11% of the total value of the building stock and associated contents. Locating this point on the risk curve suggests that this level of loss has a probability of about 0.0007 of being exceeded in any single year. This annual probability corresponds to a return period of around 1,500 years for the 1989 Newcastle earthquake, and for other events that would have a similar impact on Newcastle and Lake Macquarie.

The majority of the earthquake risk in the study region is from events that have probabilities of occurrence in the range of 0.02 to 0.001 (return periods of 50 - 1,000 years). This suggests that the risk to the region is primarily from relatively infrequent events with low or moderate impacts. In contrast, very frequent events will have low impacts, and consequently they pose little risk to Newcastle and Lake Macquarie. Very high impact events could also occur in the region. However, because these events are extremely rare they pose little risk to Newcastle and Lake Macquarie.

The risk curve allows us to obtain an estimate of the annualised risk posed by earthquakes to the study region. The results of this study suggest that, on average, the Newcastle and Lake Macquarie region will suffer an estimated economic loss of around 0.08% per year. If we assume a value of $250,000 for an 'average' building and its contents, then the annualised loss is of the order of $24 million per year in Newcastle and Lake Macquarie. It should be noted that although this is the annualised loss for the entire study region, the annualised loss varies quite significantly from building type to building type. For example, buildings constructed from unreinforced masonry (cavity brick construction) tend to have a higher annualised loss than any other building type in the study region (Figure 5). However, there are many more timber frame buildings in the study area than unreinforced masonry buildings. Consequently, timber frame buildings make a greater contribution to the total risk in the study region than unreinforced masonry buildings.

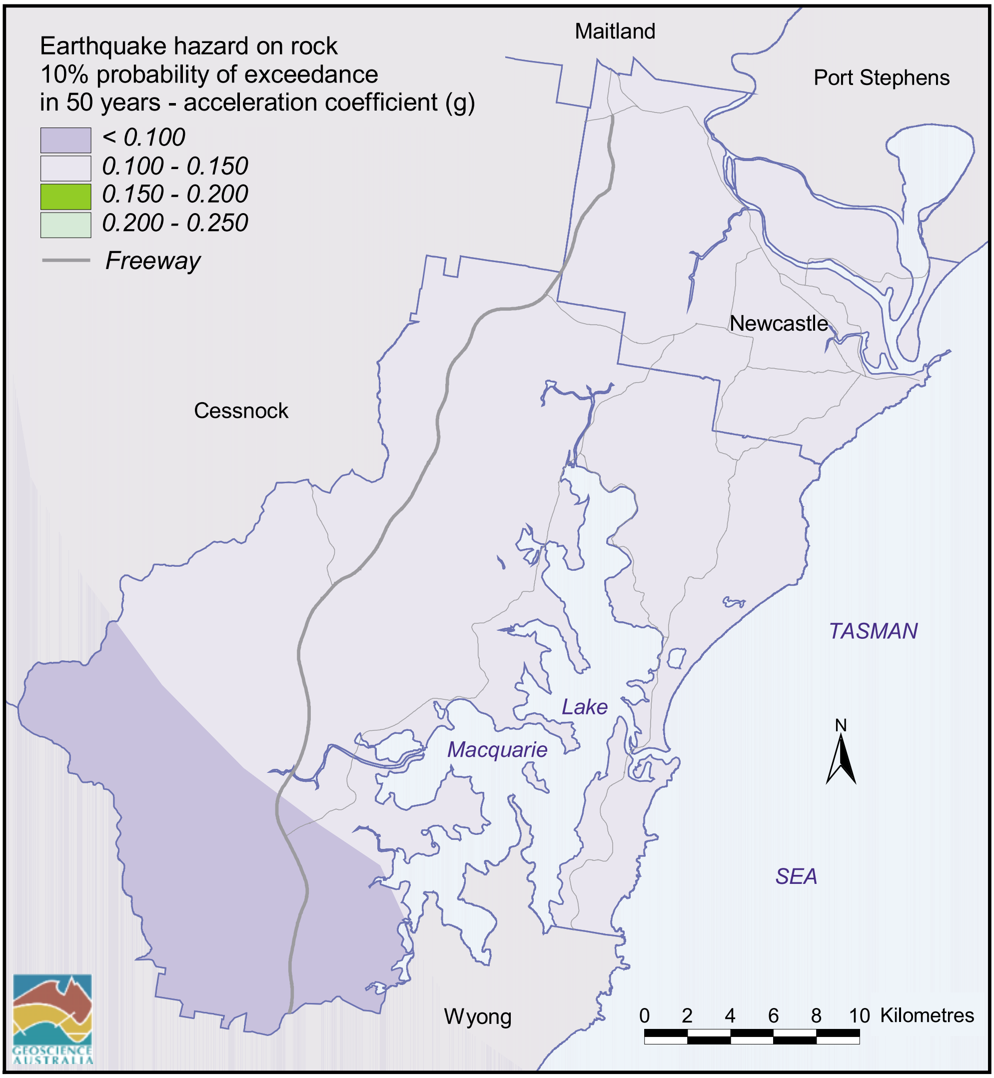


**Figure 2 (a):** Earthquake hazard on rock in Newcastle as suggested by the Australian earthquake loading standard, AS1170.4-1993. Earthquake hazard is defined as the acceleration coefficient (considered equivalent to peak ground acceleration) that has a 10% chance of being exceeded in 50 years

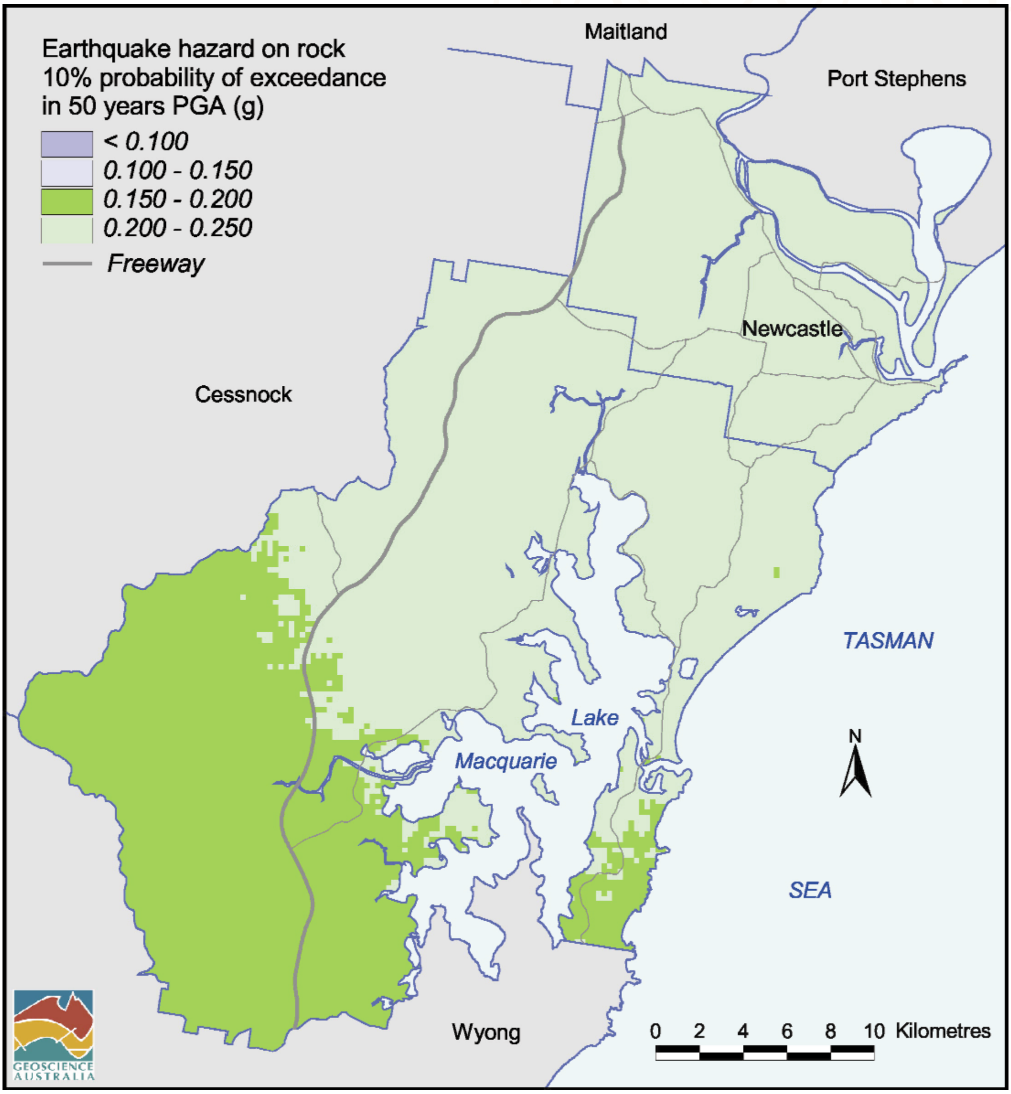


**Figure 2 (b):** Earthquake hazard on rock in Newcastle as suggested by the hazard assessment conducted for this study. Earthquake hazard is defined as the peak ground acceleration that has a 10% chance of being exceeded in 50 years

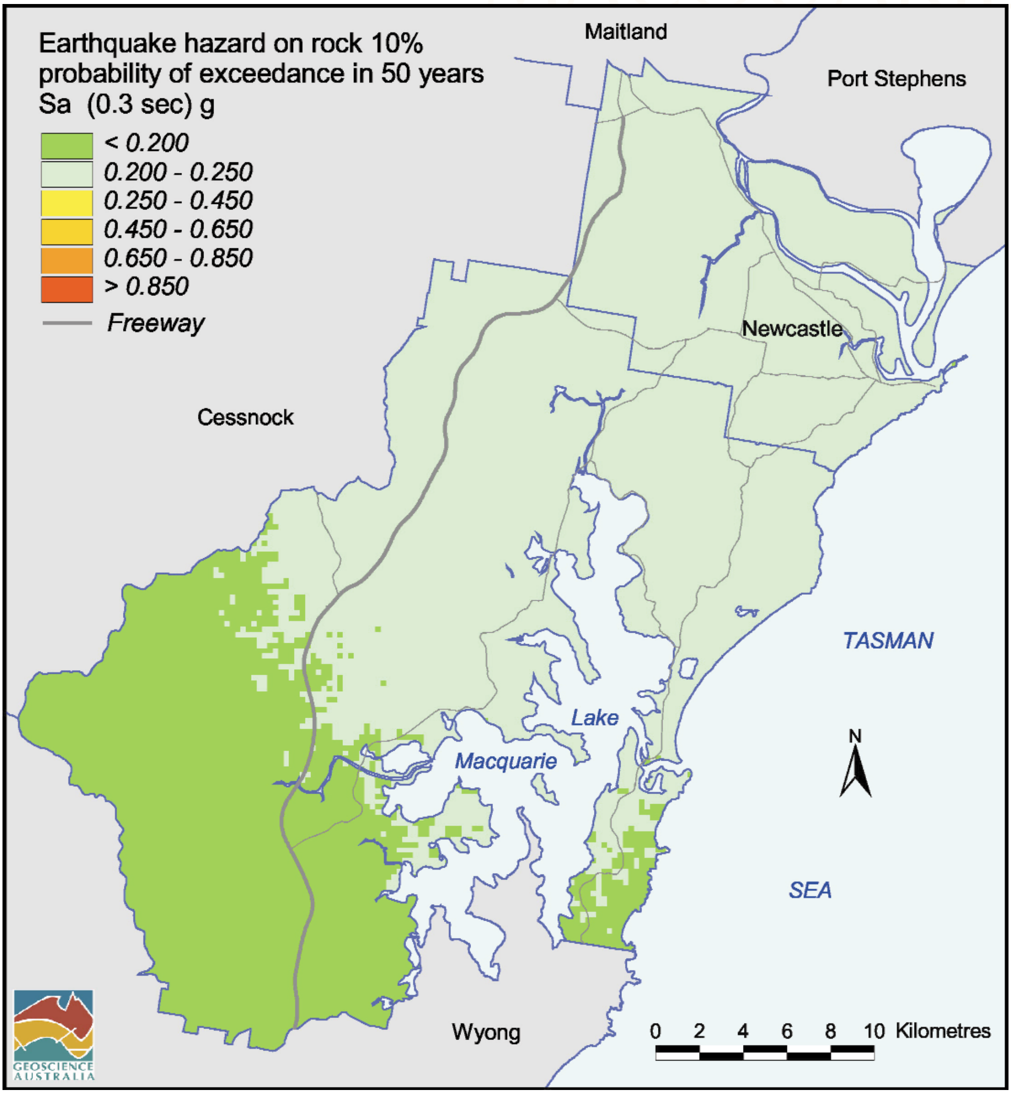


**Figure 3 (a):** Earthquake hazard map on rock with a 10% chance of being exceeded in 50 years. Hazard is defined by the response of idealised low- to medium-rise buildings with a natural period of 0.3 s

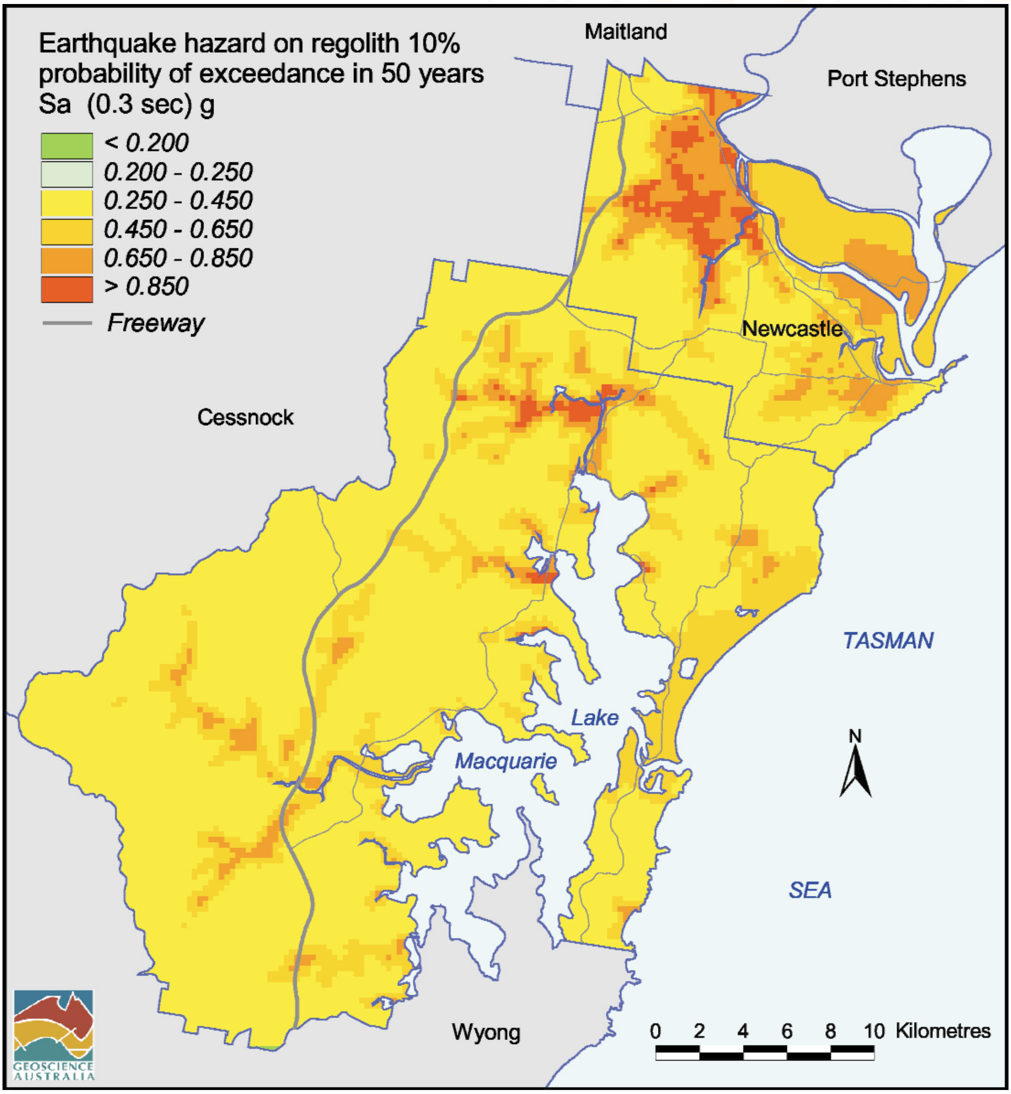


**Figure 3 (b):** Earthquake hazard map on regolith with a 10% chance of being exceeded in 50 years. Hazard is defined by the response of idealised low- to medium-rise buildings with a natural period of 0.3 s

Figure 6 presents the annualised loss by suburb, and clearly demonstrates that the loss varies spatially across the study region. This variation in loss can be partially attributed to differences in the building stock across the study region. However, the underlying regolith also affects the annualised losses, with areas that are built on substantial thicknesses of regolith, such as parts of the Newcastle municipality, having noticeably higher annualised losses than some other areas.

It is also possible to determine the relative contributions to the risk from earthquakes of different magnitudes at varying distances from the buildings within the study region. The main contributors to the earthquake risk in the study region are earthquakes with moment magnitudes around 5 at distances of less than 30 km. This result further suggests that that the majority of the risk in the region can be attributed to moderate-impact, relatively infrequent events rather than high-impact, but extremely rare, events.

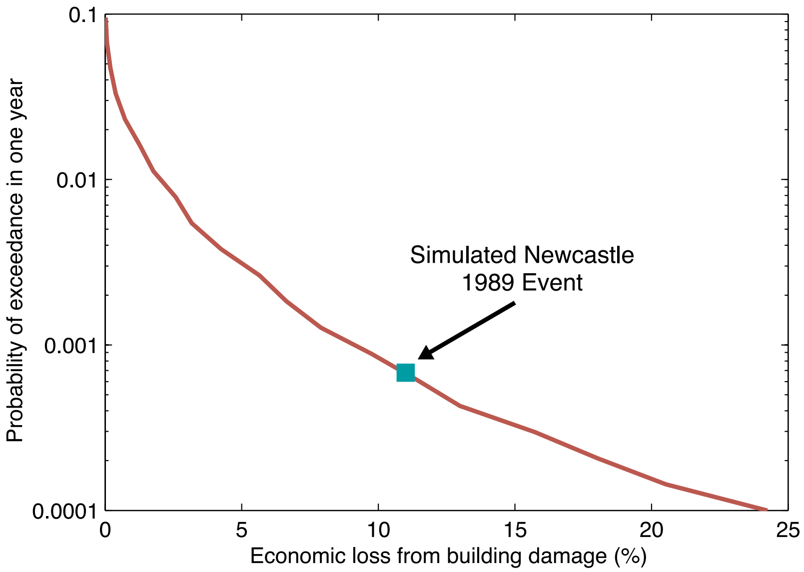


**Figure 4:** Risk curve (probable maximum loss curve) for the Newcastle and Lake Macquarie region. Economic loss is expressed as a percentage of the total value of all buildings and their contents in the study region

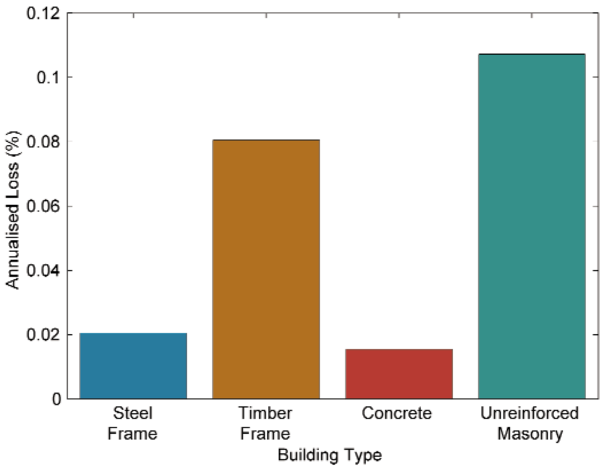


**Figure 5:** Annualised loss for a selection of building types in the study region. The annualised loss for a specific building type is described as a percentage of the total value of that building type and its contents in the study region

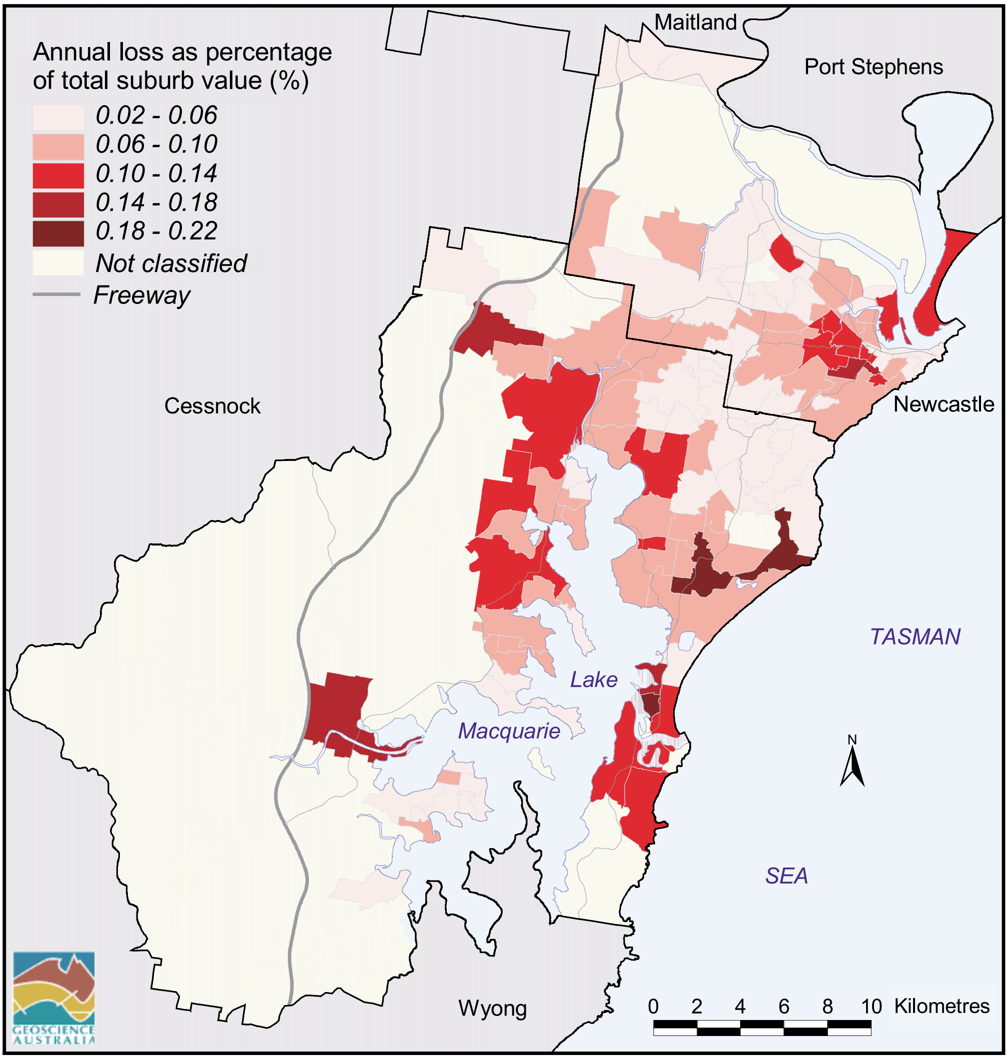


**Figure 6:** Annualised loss by suburb. The annualised loss in each suburb has been calculated as a percentage of the total value of all the buildings and their contents within the suburb. Note that some suburbs have not been classified due to the relatively low number of buildings surveyed

# Summary of Results

The key results of this work can be summarised as follows:

- The calculated earthquake hazard in the Newcastle and Lake Macquarie region is higher than the hazard suggested by the Australian earthquake loading standard, AS1170.4-1993;
- The regolith in the study region causes a significant increase in the earthquake hazard, and differences in the regolith thickness can cause quite dramatic variations in the hazard and risk across the study region;
- The annualised loss for the study region is of the order of $24 million per year;
- The majority of the earthquake risk in the study region is from events that have annual probabilities of occurrence in the range of 0.02 to 0.001 (return periods of 50 - 1,000 years);
- The risk varies with building construction type, and unreinforced masonry structures have higher average risks per building than other construction types;
- Brick veneer buildings contribute about half of the total risk. This is partly because they comprise a large proportion of buildings in Newcastle and Lake Macquarie. Timber frame buildings with timber, fibro and other light wall claddings contribute approximately one-quarter of the risk. A further one-sixth of the risk is contributed by unreinforced masonry buildings;
- Damage to residential buildings contributes the majority of the risk;
- About half of the earthquake risk is from moderate-magnitude earthquakes, with moment magnitudes around 5, that occur less than 30 km from the study area;
- The 1989 Newcastle earthquake had an economic impact with a return period of the order of 1,500 years;
- In general, the risk of casualties from earthquakes is low. However, we do not rule out the possibility that casualties in future events could be caused by damage to a single building, or a small number of buildings. It is extremely unlikely that any event capable of causing widespread casualties will occur in the study region.

It should be emphasised that a great deal of variability was included in the models used to generate these results. To some degree this variability was incorporated to account for our lack of knowledge about the various models used in the study. The effect of high levels of variability is to increase the estimates of risk. Future studies on the earthquake risk in the region should focus on improving the models that have been used. This will allow for the variability in the models to be decreased, which will most probably result in a decrease in the estimated risk.

# Conclusions

In general, the level of risk calculated within the study area is low to moderate. Based on the calculated levels of risk, some mitigation strategies that could be adopted by individuals or organisations are:

- *Improve* earthquake loading standards;
- *Enforce* the compliance of all new structures with current earthquake loading standards;
- *Provide* adequate insurance against earthquakes;
- *Protect facilities* such as police, fire and ambulance stations and hospitals, which provide essential services following any earthquake event. These facilities should be examined by suitably qualified engineers on a site-by-site basis to assess their performance under earthquake loadings. The survey of essential facilities carried out during this study found that many of these facilities were built on regolith site classes that dramatically increased earthquake hazard and/or were of vulnerable construction types.

The risks of death and serious injury are small. However, the acceptance of death or severe injury due to rare disasters such as earthquakes appears to be lower than the acceptance of more common causes of casualties such as heart disease and vehicle accidents.

Good building practice may be the single, most important, long-term factor in reducing economic losses and casualties from earthquakes in Newcastle and Lake Macquarie.

# Final Remarks

In this study, we have assessed direct economic losses due to building damage. Our study has not addressed the direct losses from business interruption or the indirect losses to other communities resulting from earthquakes in Newcastle and Lake Macquarie. An assessment of these losses would give a more complete estimate of the total risk due to earthquakes in Newcastle and Lake Macquarie.

The importance of the impacts of earthquakes on 'lifelines' such as electric power and water supply needs to be investigated. This investigation needs to address the impact that earthquakes could have on lifeline function, as well as the consequent impact on the broader community due to impaired lifeline functioning. The 1989 event demonstrated the vulnerability of economic activity to the electric power supply. Had the 2½ hour loss of electric power extended, economic costs would have been hundreds of millions of dollars greater.

The estimates of risk in this report are dependent on the models that we have used, and changes in our assumptions will alter our estimates of risk. Nonetheless, the techniques and results described in this report form a sound basis for understanding earthquake risk in Newcastle and Lake Macquarie. The techniques applied here can also be applied to other urban communities in Australia and elsewhere.

As a final note it should be remembered that, in the aftermath of the 1989 earthquake, there were many studies and recommendations on what should be done to mitigate the effects of future earthquakes. However, thirteen years on, few of the recommendations have been implemented. We urge the relevant authorities to review the recommendations made in this report and previous reports such as that conducted by the Institution of Engineers[4] and to take appropriate action, so that ultimately we will have safer and more prosperous communities.

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4 Melchers, R. E., 1990. Newcastle Earthquake Study: The Institute of Engineers, Australia; ACT, Australia.

# Notes

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