2 INTRODUCTION - URBAN GEOHAZARD RISK ASSESSMENT (D. STEWART AND T. JONES)

2.1 Newcastle & Lake Macquarie Project

This report provides details of investigations and research into the risks that are presented by earthquakes to the Newcastle and Lake Macquarie communities (Figure 2.1). The process of investigating the risk from earthquakes has led the team to recognise the risk to these same communities from a range of natural hazard phenomena. Though they were not investigated, these other natural hazards, which can be acute (ie. potentially fatal or resulting in high economic loss) include floods, landslides, severe storms and bushfires.

This report summarises the technical work carried out by Geoscience Australia on earthquake risk in the Newcastle and Lake Macquarie area. It will be a primary resource for those who have a responsibility or an interest in the management of geohazard risks within the communities of the study area. This includes local and district emergency managers, elected Council officials, and State and Council asset managers, engineers and planners, and managers and operators within the private sector who have a care or concern for life and community well-being. But principally it will be the starting point for Geoscience Australia in its new program of work extending the science supporting risk analysis in the geohazards area.

This Newcastle & Lake Macquarie study is the fifth in a series being undertaken under the Geoscience Australia *National Geohazards Vulnerability of Urban Communities Project*, more commonly referred to as the *Cities Project*. Geoscience Australia and its research partners see this regional study as providing the foundation on which communities of the Lower Hunter region can develop strategies to mitigate those risks and to cope with the impact of hazards when they occur. It builds on *Cities Project* multi-hazard risk assessment work already published on the Queensland centres of Cairns (Granger et al., 1999), Mackay (Middelmann and Granger, 2000) and south-east Queensland (Granger and Hayne, 2001).

Cities Project case studies clearly represent pioneering research. As such the results they present will undoubtedly change as better information, techniques and tools develop. We are confident, none-the-less, that this study is as accurate, scientifically sound, realistic and as practical as can be made at this stage in the evolution of 'risk science'. We encourage readers to view this report as a starting point, rather than an end in itself and we welcome feedback on any aspect covered in our reports.

It must be emphasised at the outset that this report represents a broad 'reconnaissance' of the hazards and the risks that they pose. It is not intended to be used, nor should it be used, to assign measures of risk to individual properties – the scale, resolution and accuracy of the data available to us does not support such precision. The report should therefore be seen as the first step in the process of comprehensive community risk management. The next steps are discussed later in the report and will extend the science of geohazard risk assessment. They will also involve the Newcastle and Lake Macquarie communities and the NSW State government .

2.2 The Cities Project

The *Cities Project* was established in 1996 to undertake research directed towards the mitigation of the risks faced by Australian urban communities that are posed by a range of geohazards. *The ultimate objective is to improve the safety of communities, and consequently make them more sustainable and prosperous.* It formed a significant part of Australia's contribution to the International Decade for Natural Disaster Reduction (IDNDR) which ran through the 1990's and continues to be a focus for Commonwealth community risk research. It can also be seen as a response to the findings of the 1993 Senate Inquiry into Major Disasters and Emergencies (Senate, 1994). In its findings, the Senate Committee encouraged the emergency management community to modify its doctrine from one that had been traditionally dominated by attention to disaster response, to one which gives greater attention and emphasis to risk mitigation and the reduction of community vulnerability.

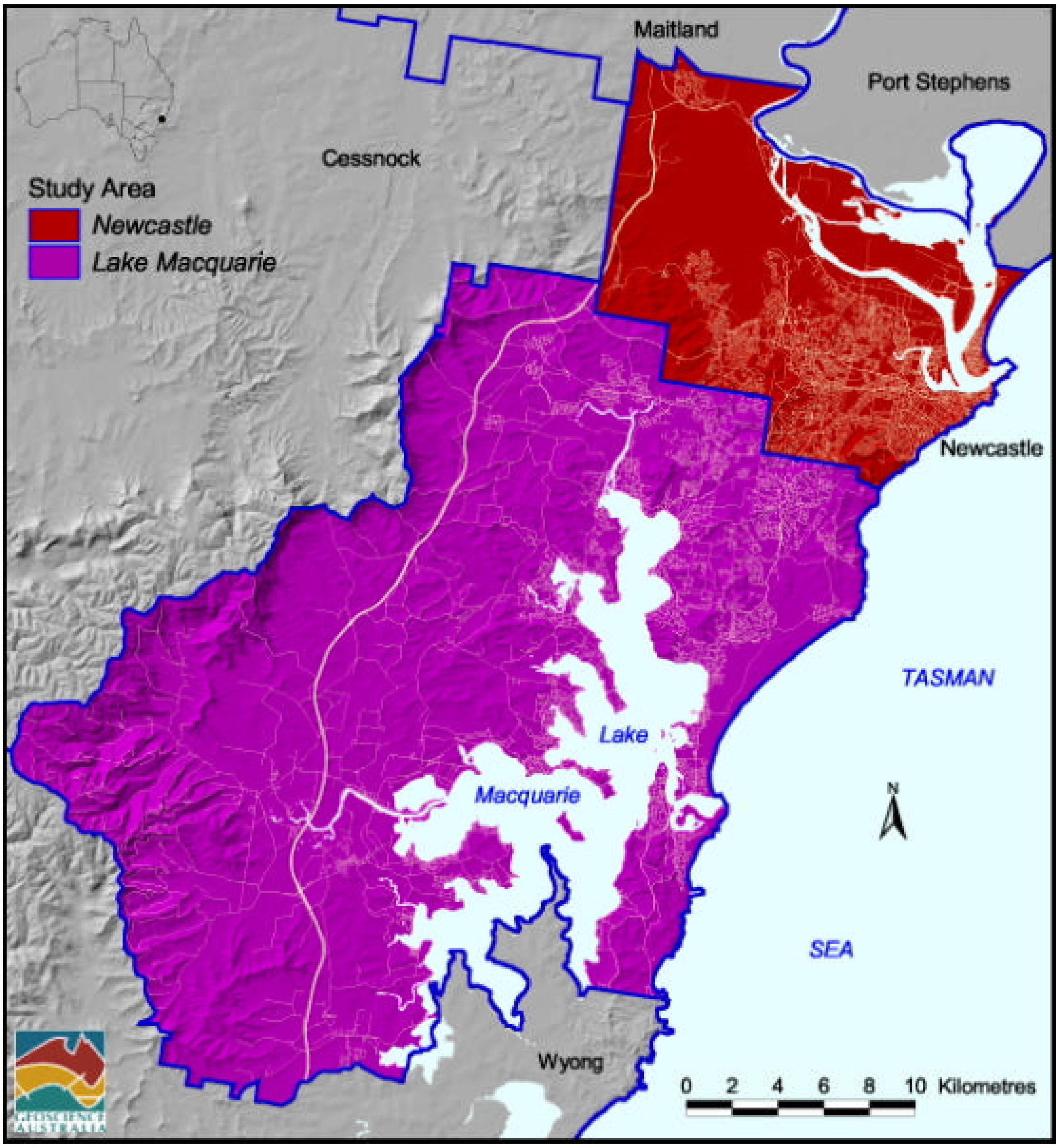

Figure 2.1: The study area of Newcastle and Lake Macquarie

Such a broadly-based program of research obviously requires a multi-disciplinary approach. To enable Geoscience Australia, a research agency traditionally focused on earth science, to achieve the objectives set for the *Cities Project*, a network of operational, research and supporting partners has been developed. We have been most fortunate in attracting the commitment of partners of great quality and enthusiasm. They span a very broad range of scientific disciplines, administrative responsibilities and industry sectors. Of particular value has been the close collaboration with:

Newcastle City Council

Lake Macquarie City Council

The Insurance Council of Australia

AON Reinsurance

Emergency Management Office, Hunter Region

Hunter Water Corporation

The University of Newcastle

2.3 Risk Management

The concept of risk, and the practice of risk management, received a significant boost in Australia with the publication of the Australia and New Zealand Risk Management Standard in 1995 and its subsequent revision as *AS/NZS 4360:1999 Risk Management* (AS/NZS4360, 1999). This generic guide provides the philosophical framework within which the *Cities Project* studies have been developed. That process is outlined in Figure 2.2.

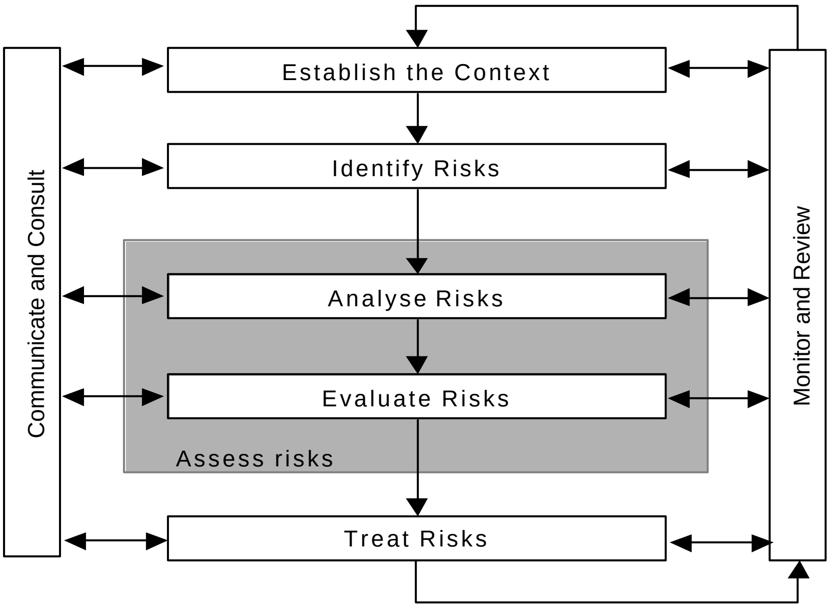

Figure 2.2: Risk management overview (adapted from (AS/NZS4360, 1999))

This study deals largely with the risk identification and risk assessment (ie. the “analyse” and “evaluate”) stages of the process. Whilst we provide some opinion on matters relating to risk treatment, these are the responsibility of those, such as the local governments and the New South Wales Government agencies, that have that statutory role.

2.4 What is Risk?

The risk management Standard defines ‘risk’ as:

“the chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood”

This definition is really too general for our purposes, consequently we have chosen to follow the conceptual basis and definitions developed under the Office of the United Nations Disaster Relief Coordinator (UNDRO) in 1979 and cited by Fournier d’Albe (Fournier d'Albe, 1979) as follows:

- ***Natural hazard*** *means the probability of occurrence, within a specified period of time in a given area, of a potentially damaging natural phenomenon.*
- ***Vulnerability*** *means the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude…*
- ***Elements at risk*** *means the population, buildings and civil engineering works, economic activities, public services, utilities and infrastructure, etc., at risk in a given area.*
- ***Specific risk*** *means the expected degree of loss due to a particular natural phenomenon: it is a function of both natural hazard and vulnerability.*
- ***Risk*** (ie. ‘total risk’) *means the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon, and consequently the product of specific risk and elements at risk.*

Total risk can be expressed simply in the following pseudo-mathematical form:

Equation 2-1: Risk framework

$$\begin{gathered}\text{RISK}\\=\\\text{HAZARD}\\*\\\text{ELEMENTS AT RISK}\\*\\\text{VULNERABILITY OF THE ELEMENTS AT RISK TO THE HAZARD}\end{gathered}$$

Here the * symbol does not mean multiplication, but some unspecified way of combining the various quantities.

This approach is not only elegant, it is also very practical. Given the complexity of urban communities and the degree to which the various elements at risk are interdependent, the ‘total risk’ approach is considered mandatory. Further, it also lends itself to quantitative, qualitative and composite analytical approaches.

Risk mitigation (ie. moderating the severity of a hazard impact) is the principal objective of risk management. In this context, risk mitigation might be seen as:

> *“the process by which the uncertainties that exist in potentially hazardous situations can be minimised and public (and environmental) safety maximised. The objective is to limit the human, material, economic and environmental costs of an emergency or disaster, and is achieved through a range of strategies ranging from hazard monitoring to the speedy restoration of the affected community after a disaster event”*
>
> after Granger (Granger, 1988; Granger, 1993)

It is clear that uncertainty is a key factor. Indeed, it can be argued that, in many instances, the effectiveness of risk mitigation strategies is inversely proportional to the level of uncertainty that exists. The risk management process, particularly the risk analysis and risk evaluation stages, is clearly aimed at developing the best and most appropriate information with which to reduce that uncertainty. The amount of total risk may be diminished by reducing the size of any one or more of the three variables – the hazard, the elements exposed and their vulnerability.

2.5 Risk Identification

A detailed understanding of what events have occurred in the past (including prehistoric events) and their effects provides the basis for understanding what could or will happen in the future, ie. it is the key step in the risk identification process. To this end, Geoscience Australia has developed catalogues on historic earthquakes and the Insurance Council of Australia, Emergency Management Australia and some local councils (amongst others) maintain some data on the losses associated with such events. Throughout this report we provide details of the known history of earthquake impacts in Eastern Australia in general and Newcastle and Lake Macquarie Cities in particular. This history is not only important in establishing levels of probability for future events but also to illustrate that such threats are very real.

It is worth reflecting that major disasters (excluding drought) cost Australia, as a nation, on average $1.1 billion annually between 1967 and 1999, with earthquakes contributing to approximately 13% of this figure (BTE, 2001). The known fatalities attributed to natural hazards also helps to put them into perspective as shown in Table 2-1.

Table 2-1: Fatalities in Australia caused by natural hazards (based on Coates (Coates, 1996) and Geoscience Australia data)

Natural Hazard	Period Covered	Fatalities
Heatwaves	1803 – 1992	4,287
Tropical cyclones	1827 – 1989	1,863 – 2,312 [2]
Floods	1803 – 1994	2,125
Bushfires	1827 – 1991	678
Lightning strikes	1803 – 1992	650
Landslides	1803 - 1999	83
Earthquakes	1803 - 1999	15

The real number of fatalities is almost certainly greater than listed, given that the statistics in the table were derived largely from reports contained in the Sydney Morning Herald and its predecessor, the Sydney Gazette. Nevertheless, they confirm that we do not live in an especially benign environment.

Monitoring and surveillance: One of the principal sources of historical hazard event information and hazard phenomenon knowledge is the extensive network of monitoring stations and remote sensing resources that have been established. In this regard, Geoscience Australia has access to more than 150 seismographs across Australia.

2.6 Risk Analysis

AS/NZS 4360:1999 (AS/NZS4360, 1999) defines 'risk analysis' as:

> *"a systematic use of available information to determine how often specified events may occur and the magnitude of their likely consequences."*

The focus of hazard science research is on the mechanisms that cause, create, generate or drive the hazard phenomena, eg. what causes earthquakes and what influences the transmission of their energy through various geological strata. This is underpinned by information relating to the background geological aspects of the site that are relevant to hazard studies, eg. the depth and nature of the sediments and their likely behaviour under earthquake shaking. Whilst there is little that can be done to eliminate or reduce the severity or frequency of these phenomena, a good understanding of what drives them enhances our ability to forecast or predict their behaviour. It is also fundamental to establishing an understanding of event probabilities.

Elements at risk and their vulnerability is a relatively new area of study and is focused on developing an understanding of the vulnerability of the wide range of elements that are at risk within the community eg. the people and their physical and social infrastructures. It involves disciplines as diverse as geography, demography, psychology, economics and engineering. A significant effort has been made to develop very detailed data on the principal elements at risk in the built environment of Newcastle and Lake Macquarie. Also, the development of vulnerability models, which predict the impact of earthquakes with sufficient accuracy, is a key component of the research undertaken.

In an effort to address the diverse range of applications to which the output from risk scenarios may be put, we have adopted the practice of running a range of earthquake scenarios. These typically extend from the relatively small and more frequently occurring events, to those in the so-called 'maximum probable' or 'maximum credible' range. Each earthquake scenario is associated with a probability of occurrence, and hence probabilistic loss curves and annualised loss estimates can be generated.

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[2] *minimum and maximum estimates which also include approximately 170 flood fatalities*

2.7 Risk Evaluation

AS/NZS 4360:1999 (AS/NZS4360, 1999) defines ‘risk evaluation’ as:

> *“the process used to determine risk management priorities by evaluating and comparing the level of risk against predetermined standards, target risk levels or other criteria.”*

Before risks can be evaluated, a basic understanding of probability is required.

A common description of event probability is the so-called ‘return period’ of a particular phenomenon, typically given in a form such as a ‘1-in-1,000 year earthquake’. Not only are such figures typically based on less than 1,000 years of record, it has been widely reported that such an expression of probability is prone to be misinterpreted and misused. Description of an event as a ‘1 in 1,000 year event’ is frequently taken (wrongly) to indicate that there will not be another such event for another 1,000 years.

Another term used for ‘return period’ is the ‘average recurrence interval’ (ARI). This latter term describes more accurately what is meant by ‘return period’. A correct interpretation of the term ‘return period’, would be that an earthquake of magnitude ‘X’ or greater occurs, on average, once every 1,000 years, for example. On an annual basis, this is approximately equivalent to an annual probability of exceedence (AEP) of 0.1% (1/1000).

Within a given period of n years, the probability of exceedance of an event with a given ARI is given in Table 2-2. It should be noted that, within n years, the probability of more than one event is implicitly considered. For n=1, the probability calculated is precisely the AEP.

It is easy to see that the short term risk of a developer, or an elected official, whose exposure is typically from three to five years, will be considerably less than that of a householder or company (say 25 to 50 year exposure), or individual (perhaps a 100 year exposure).

In the approach to risk assessment set out in AS/NZS4360 (AS/NZS4360, 1999), it is the practice to compare the level of risk found during the assessment process with previously established risk criteria. This practice enables the judgement of whether the risk is ‘acceptable’ (or at least tolerable) or not. Levels of acceptability, or risk aversion, are built into such things as urban planning design constraints and the Australian Building Code, where criteria are based on ‘design levels’. For example, under the earthquake loading code, AS1170.4-1993 Minimum design loads on structures Part 4: Earthquake loads (AS1170.4, 1993), the ‘design level of earthquake shaking’ is one in which there is an estimated 10% probability of the ground motions being exceeded in a 50 year period, ie. the acceptability criterion is set at a 10% chance of exceedance over the nominal lifetime of a typical building.

Not all acceptability criteria can be expressed as categorically as those outlined in the Building Code because they deal with human nature and the political outrage dimension of risk management. There is a considerably lower aversion to risks that are ‘voluntary’, ie. those willingly undertaken by individuals, such as air travel or smoking, than there is to those that are seen as being ‘involuntary’, many of which carry a significantly lower risk. For example, in NSW, the chances of a fatality occurring from smoking 20 cigarettes a day has been calculated as being 5,000 per million people per year and for travel by motor vehicle as 145 chances per million people per year. By contrast, the chances of fatality from ‘cataclysmic storms and storm floods’ is calculated as 0.2 chances per million per year and lightning strike as 0.1 per million people per year (Higson,). Such expressions of risk, in terms of annual probability, are very useful since they incorporate the effects of rarer and more common events.

Similar information is shown graphically in Figure 2.3.

The acceptability criteria for economic risk are an important issue. Different people will have different levels of risk averseness to earthquake induced economic losses. For example, many do not consider earthquakes to be a threat at all. For those who do consider the risk, the level of risk acceptability will be often influenced by the cost of reducing risk through mitigation.

The level of risk acceptance also varies considerably over time. The threshold of acceptance is typically much lower immediately after a hazard impact, for example, than it was immediately before the impact. The existence of changing and conflicting frames of reference reinforces the need for a strong feedback mechanism between establishing acceptability and formulating risk mitigation and response strategies. In developing risk management options and strategies, the competing value systems and expectations of these various frames of reference need to be taken into account.

The acceptability factor is central to the process of risk prioritisation. This is the first step in the allocation of resources to risk mitigation, especially if considered in a multi-hazard context.

Table 2-2: Probability of exceedance in n years

Probability of exceedence		Return period (years)						
		100	200	475	1,000	2,000	5,000	10,000
n years considered	1	1.00%	0.50%	0.21%	0.10%	0.05%	0.02%	0.01%
	2	1.99%	1.00%	0.42%	0.20%	0.10%	0.04%	0.02%
	5	4.90%	2.48%	1.05%	0.50%	0.25%	0.10%	0.05%
	10	9.56%	4.89%	2.09%	1.00%	0.50%	0.20%	0.10%
	20	18.21%	9.54%	4.13%	1.98%	1.00%	0.40%	0.20%
	50	39.50%	22.17%	10.00%	4.88%	2.47%	1.00%	0.50%
	100	63.40%	39.42%	19.00%	9.52%	4.88%	1.98%	1.00%
	200	86.60%	63.30%	34.39%	18.14%	9.52%	3.92%	1.98%
	500	99.34%	91.84%	65.14%	39.36%	22.12%	9.52%	4.88%
	1,000	100%	99.33%	87.85%	63.23%	39.35%	18.13%	9.52%
	2,000	100%	100%	98.52%	86.48%	63.22%	32.97%	18.13%
	5,000	100%	100%	100%	99.33%	91.80%	63.22%	39.35%
	10,000	100%	100%	100%	100%	99.33%	86.47%	63.21%

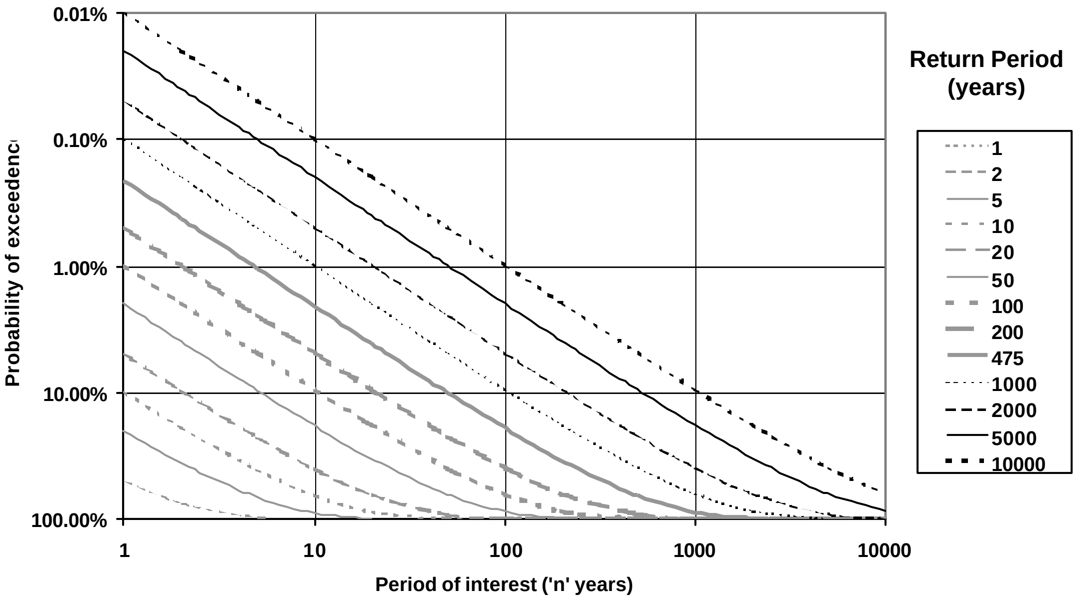

Figure 2.3: Probability of exceedance for a given return period event occurring in n years

2.8 Risk Mitigation Strategies

While the role of Geoscience Australia and the Cities Project is concerned primarily with risk identification and assessment, the following processes provide some insight into the risk mitigation process.

An effective forecasting system, combined with a high level of community awareness and risk appreciation, is clearly one of the most potent mechanisms by which to achieve risk reduction. This embraces the longer-term estimates of the 'hazardousness' of areas such as those contained in the earthquake hazard (acceleration coefficient) maps that accompany AS1170.4 (AS1170.4, 1993), or by hazard and risk maps specifically prepared as has been performed in this study.

Risk assessments are made so that strategies may be developed that will ultimately lead to the elimination, reduction, transfer or acceptance of the risks, and to ensure that the community is prepared to cope with a hazard impact. While the development and implementation of these strategies lie essentially outside the scope of the Cities Project, our experience in working with emergency managers and others to date suggests that some of the most effective strategies are:

- a strong risk management culture;
- well maintained and appropriate information about risk, linked to comprehensive monitoring systems;
- wide-spread and ongoing community awareness programs based on risk history, scenario analysis and an effective risk communication capability;
- emergency management plans, resources, training and decision support tools based on risk assessments;
- risk-based planning of settlement, development and the siting of key facilities (such as hospitals);
- protection plans for key facilities and lifelines;
- appropriate and enforced building and planning codes; and
- cost-effective engineered defences such as retrofit programs.

2.9 Confidence, Uncertainty and Probability

The analysis of issues as complex as community risk is highly dependent on the accuracy, currency and appropriateness of the data and models that it employs. Every effort has been made to ensure that the best available data and models have been used in the various analyses included in this study. For the most part, the results of modelling and other forms of analysis have been subjectively examined for 'reality' against recordings of the 1989 Newcastle earthquake and the experience of the authors and a good number of reviewers with appropriate local knowledge and experience.

2.10 Earthquake Risk Assessment Methodology Adopted for this Study

The overall risk assessment methodology used in this study can be summarised by the flowchart in Figure 2.4. Chapters 3 and 4 of this report cover the hazard components of the risk process. The elements at risk and their vulnerability are considered in Chapter 5. The verification of the impact modelling process using records of the 1989 Newcastle earthquake as well as the final risk assessment results are presented in Chapter 6.

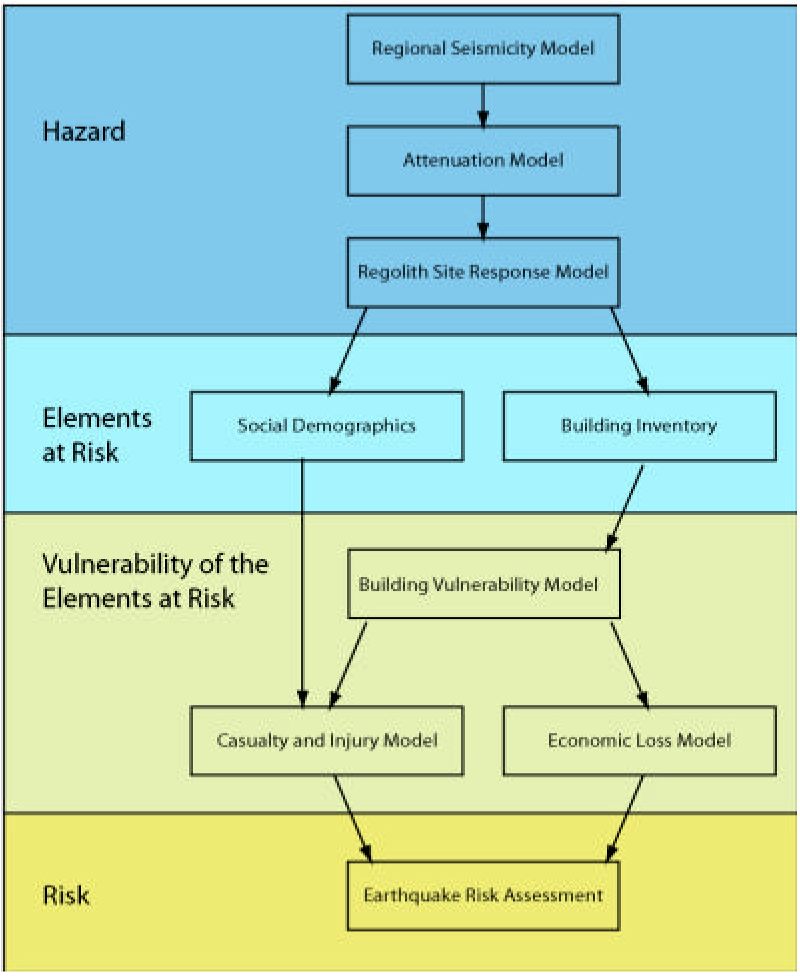

Figure 2.4 : Flowchart of the risk assessment methodology