CHAPTER 1: URBAN GEOHAZARD RISK ASSESSMENT

This Report

This report provides details of the first comprehensive report of the risks faced by the Cairns community that are posed by a range of natural hazard phenomena. It has been developed as a primary resource for those who have a responsibility and interest in the management of those risks. Those individuals and groups span a very wide spectrum from the individual concerned citizen, through elected officials to professional engineers, planners and emergency managers.

This is the first in a series of case studies to be undertaken under the Australian Geological Survey Organisation's (AGSO)[1] *National Geohazards Vulnerability of Urban Communities Project*, more commonly referred to as the *Cities Project*. The report should be seen as the first step in the process of comprehensive community risk management. We see it as providing the foundation on which the Cairns community can build its strategies to mitigate those risks and to cope with the impact of hazards when they occur. It is also intended to provide a model for other communities in Australia and elsewhere. We encourage readers to view it as a starting point, rather than an end in itself.

This is a pioneering study. As such it will undoubtedly change as better information, techniques and tools develop. We are confident that it is as accurate, scientifically sound, realistic and practical as it can be made at this stage in the evolution of 'risk science'. We welcome feedback on any aspect covered in our reports.

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 from a range of geohazards. **The ultimate objective is to improve the safety of communities, and consequently make them more sustainable and prosperous.** It forms a significant part of Australia's contribution to the United Nations International Decade for Natural Disaster Reduction (IDNDR) which has run throughout the 1990's. It can also be seen as a response to the findings of the 1993 Senate Inquiry into Major Disasters and Emergencies (Senate, 1994) which encouraged the emergency management community to modify its doctrine from one traditionally dominated by attention to disaster response, to one which gives greater attention and emphasis to risk mitigation and the reduction of community vulnerability.

To provide a realistic focus to the research, and to achieve practical outcomes, the *Cities Project* is using a series of geohazard risk case studies based on Queensland centres to develop and test its science and techniques. Cairns is the first of these case studies.

Our view of 'geohazards' is deliberately very broad and includes ***all earth surface processes with the potential to cause loss or harm to the community or the environment***. Whilst our focus in the *Cities Project* is mainly on potentially fatal acute geohazards such as earthquakes, landslides and floods, the importance of more chronic geohazards such as acid sulphate soils, coastal erosion, reactive soils and dry land salinity is also recognised. This report, however, deals only with the acute geohazards.

Such a broadly based program of research obviously requires a multi-disciplinary approach. To enable AGSO 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

[1] A list of acronyms and abbreviations used in this report is include as Appendix A.

partners of great quality and enthusiasm. They span a very broad range of scientific disciplines, administrative responsibilities and industry sectors, as can be seen from the list in Appendix B. Of particular value has been the close collaboration with Cairns City Council, the Queensland Department of Emergency Services and researchers involved in the Tropical Cyclone Coastal Impacts Program (TCCIP), a multi-agency and multi-disciplinary research program coordinated by the Bureau of Meteorology. The risk management approaches adopted under both the *Cities Project* and TCCIP are essentially identical.

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 Standard *AS/NZS 4360:1995 Risk management* (Standards Australia, 1995). This generic guide provides the philosophical framework within which the *Cities Project* studies are developed. That process is outlined in **Figure 1.1**.

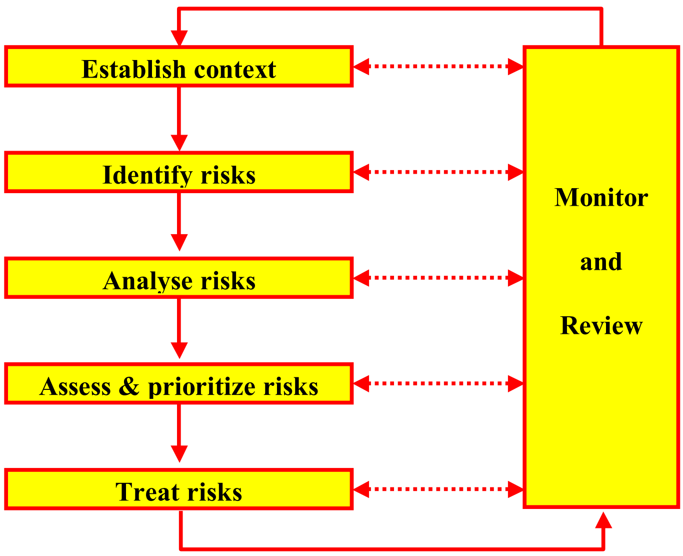

Figure 1.1: Risk management overview (Standards Australia, 1995, Fig 3.1)

This study deals largely with the risk identification, risk analysis and risk assessment stages of the process. Whilst we provide some opinion on matters relating to risk prioritisation and risk treatment these are the responsibility of those, such as the Cairns City Council and the Queensland Government agencies, that have that statutory responsibility.

What is Risk?

Standard *AS/NZS 4360:1995* 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 developed under the Office of the United Nations Disaster Relief Coordinator (UNDRO) in 1979 and cited by Fournier d'Albe (1986) 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*** (i.e. '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:

$$\textbf{Risk}_{\textbf{(Total)}} = \textbf{Hazard x Elements at Risk x Vulnerability}$$

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 (i.e. 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 from hazard monitoring to the speedy restoration of the affected community after a disaster event*** (after Granger, 1989 and 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 assessment stages, is clearly aimed at developing the best and most appropriate information with which to reduce that uncertainty.

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, i.e. it is the key step in the risk identification process. To this end, AGSO has developed catalogues on historic earthquakes, landslides and tsunami events, the Bureau of Meteorology (BoM) maintains comprehensive collections on severe weather events such as cyclones and floods, and the insurance industry maintains some data on the loss associated with such events. Throughout this report we provide details of the known history of hazard impacts in Cairns. 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 noting that the earthquake of record occurred in 1896 when Cairns consisted of a string of perhaps a hundred timber buildings on the shores of Trinity Inlet. The flood of record occurred in 1911 when there was virtually no development on the Barron River delta. The most significant cyclone impact on record was probably that of 1920 which put a storm tide of about 1 m above high tide level through the town, the population of which was only 10% of its current level. Even the most spectacular technological disaster, Australia's first BLEVE (boiling liquid expanding vapour explosion) accident in 1987, occurred when the population of the city was less than half its current level.

Risk Analysis

AS/NZS 4360:1995 (p. 5) 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.*

We have identified three distinct aspects of this process.

***Phenomenon process knowledge*:** The focus of hazard science research is on the mechanisms that cause, create, generate or drive the hazard phenomena, e.g. what causes earthquakes and what influences the transmission of their energy through various strata. This is underpinned by information relating to the background climatic, environmental, terrain, ecological and geological aspects of the site that are relevant to hazard studies, e.g. the depth and nature of the sediments and their microtremor response. 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*:** This is a relatively new area of study and is focused on developing an understanding of the vulnerability of a wide range of the elements that are at risk within the community e.g. the people, buildings and infrastructures. It involves disciplines as diverse as geography, demography, psychology, economics and engineering. It is in this aspect that the synergy between the *Cities Project* and TCCIP has been most effective, given that the elements at risk are common, regardless of the hazard involved.

A significant effort has been made to develop very detailed data on the principal elements at risk in the built environment of Cairns, whilst comprehensive statistics of good resolution are available from the quinquennial national censuses to provide at least basic measures of human vulnerability. The broad groups of elements at risk for which data have been collected in Cairns include:

***The Setting*.** Basic regional data has been accumulated from a very wide range of custodians for themes including the physical environment (climate, vegetation, geology, soils, land use, topography, elevation, etc), access (external links by major road, rail, air, marine and telecommunications infrastructures) and administrative arrangements (local government, suburb and other administrative boundaries).

***Shelter*.** The buildings that provide shelter to the community at home, at work and at play, vary considerably in their vulnerability to different hazards. A range of information relating to their construction is required. These building characteristics contribute to the relative degree of vulnerability associated with exposure to a range of hazards. In **Table 1.1** the number of stars reflect the significance of each attribute's contribution to building vulnerability. A database containing such details on some 35 000[2] individual buildings in Cairns has been developed.

CHARACTERISTIC	FLOOD	WIND	HAIL	FIRE	QUAKE
Building age	***	*****	**	*****	*****
Floor height or vertical regularity	*****	*		****	*****
Wall material	***	***	*****	****	****
Roof material		****	*****	****	***
Roof pitch		****	***	*	
Large unprotected windows	**	*****	****	*****	**
Unlined eaves		***		*****	
Number of stories	****	**		*	*****
Plan regularity	**	**		***	*****
Topography	*****	****		****	***

Table 1.1: Relative contribution of building characteristics to vulnerability

Access to shelter is also significant, so information on mobility within the community is needed. Details of the capacity and vulnerability of the road network, for example, have been acquired.

Sustenance. Modern urban communities are highly reliant on their utility and service infrastructures such as water supply, sewerage, power supply and telecommunications. These so-called *lifelines* are significantly dependent on each other and on other logistic resources such as fuel supply.

The community is also dependent on the supply of food, clothing, medicine and other personal items. Information has been accumulated on all of these, as well as on the enterprises that wholesale, distribute and service these sectors (such as transport, material handling equipment and storage). All of the key facilities in Cairns have been identified in the *BUILDING* database and basic data on power and water supply infrastructure are available.

Security. The security of the community can be measured in terms of its health and wealth and by the forms of protection that are provided. Physically, these may be assessed by the availability of hospitals, nursing homes, industries, commercial premises, agricultural land use, ambulance stations, fire stations, police stations and works such as flood detention basins and levees. Also important are socio-demographic and economic issues related to the elderly, the very young, the disabled, household income, unemployment, home ownership and the resources available at the fire and police stations. Emergency plans are also a key component of community security.

Society. Here we find some of the more intangible measures such as language, ethnicity, religion, nationality, community and welfare groups, education, awareness, meeting places, cultural activities and so on. Some of these may be measured in terms of the facilities that they use, such as churches and sporting clubs, however, the more meaningful measures relate specifically to the individuals, families and households that make up the community.

Extensive use has been made of the detailed data from the 1996 National Census published in the *CData96* product (ABS, 1998a) to flesh out our understanding of the social, demographic and economic dimensions of vulnerability under both the 'security' and 'society' components.

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[2] Initial collection of these data on the first 20 000 buildings was made possible by a grant from the Australian Coordinating Committee for the IDNDR to the Queensland Department of Emergency Services in 1995. They have subsequently been expanded in both coverage and detail under the *Cities Project*.

Synthesis and modelling: Clearly, the range and variety of information needed to fuel a comprehensive risk analysis is enormous. While there are now many sources for such, much of it with the essential spatial and temporal attributes needed, there remain important gaps. Our knowledge of hazard phenomena and the processes that drive them, for example, are far from perfect. It is necessary, therefore, to develop appropriate models to fill the knowledge gaps. Some hazards, such as bushfires and floods, have an established body of modelling research behind them, whilst others, such as cyclones and earthquakes are, as yet, less well served.

A key aspect of these models is an understanding of the probability of recurrence of events of particular severity and the levels of uncertainty that exist in both the data employed and the models themselves. Given these uncertainties, we remain cautious about presenting most of our findings as anything more than *indications* of what the future may hold.

The synthesis of data and the essential mapping of the spatial relationships between the hazard phenomena and the elements at risk requires the use of tools such as geographic information systems (GIS). In the work undertaken in the Cairns case study, at least 90% of the information used has some form of spatial content. Similarly, the relationships that are most significant in risk analysis and risk assessment are largely spatial. To accommodate this spatial emphasis, the *Cities Project* makes extensive use of GIS tools and technologies.

Whilst GIS have been used over the past decade as tools to address specific aspects of the risk management problem, especially in hazard mapping and the spatial modelling of phenomena such as bushfires or storm tide inundation, there are few examples of integrated risk management applications. There are obvious advantages in developing a fusion between a philosophy of risk management and the power of GIS as a decision support tool, hence *Risk-GIS*, as it has been christened in the *Cities Project*. As such *Risk-GIS* provides the analytical 'engine' which drives the *Cities Project's* urban geohazard risk assessment process. *Risk-GIS* also provides a most potent form of risk communication through its capacity to provide a visual representation of risk situations. All of the maps and many of the diagrams and tables included in this report are output from the *Risk-GIS*. A more detailed discussion of *Risk-GIS*, the data used and the information infrastructure that supports it, is given in Granger (1998).

Risk Assessment and Prioritisation

AS/NZS 4360:1995 (p. 5) defines 'risk assessment' as:

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

We see two key components of this.

Scenario analysis: This is an emerging technique that contributes to 'future memory', an understanding of *what will happen when….* The output embraces forecasts or estimates of community risk including economic loss and potential casualties, or assessments of the impact of secondary or consequential hazards, such as the spread of fire or the release of hazardous materials following an earthquake. It also provides essential input to both the development of risk treatment strategies and to framing long-term forecasts or estimates.

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 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.

Acceptability: In the approach to risk assessment set out in *AS/NZS 4360:1995*, it is the practice to compare the level of risk found during the assessment process with previously established risk criteria, so that it can be judged whether the risk is 'acceptable' or not. At first glance this may seem to be something of a chicken-and-egg process - if you do not know what the level of risk posed by earthquake is in Cairns, for example, how can you realistically determine what level of risk is acceptable?

Levels of acceptability are, however, built in to 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 Earthquake Loads* (Standards Australia, 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, i.e. the acceptability criterion is set at a 10% chance of exceedence over the nominal lifetime of a typical building.

Not all acceptability criteria can be expressed as categorically as this because they deal with human nature and the political *outrage* dimension of risk management. They also vary considerably over time. The threshold of acceptance is typically much lower immediately after a hazard impact than it was immediately before the impact. This reinforces the need for a strong feedback mechanism between establishing acceptability and the formulation of risk mitigation and response strategies.

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. We are beginning to address the complex issue of comparing the risks posed by hazards with greatly different impact potential. In Cairns, for example, there is a strong spatial correlation between the areas that are most at risk from major inundation hazards (river flooding, storm tide and tsunami) and those in which deep soft sediments are most likely to maximise earthquake impact. Conversely these are the areas that are at least risk from landslide impact and, to some degree, from severe wind impact. Additionally, the impact on the Cairns community of a cyclone hazard with an average recurrence interval (ARI) of once in 150 years is likely to be more severe than the impact of the shaking associated with an earthquake with an ARI of 150 years. The maximum credible earthquake event, however, may have a greater potential for catastrophe, than the maximum credible cyclone.

The ultimate responsibility for determining what levels of risk are 'acceptable' rests with the Cairns community and the Cairns City Council.

Risk Mitigation Strategies

Whilst the role of AGSO and the *Cities Project* is concerned primarily with risk identification, analysis and assessment, these processes provide some insight into the risk mitigation process.

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 across Australia. For example, AGSO has access to more than 150 seismographs across the country, whilst the Bureau of Meteorology maintains some 45 weather radar sites, 246 automatic weather stations and 3,029 stream gauging stations. The Bureau also takes data from the Japanese Geostationary Meteorological Satellite 26 times a day in addition to data taken from the polar orbiting US NOAA.

Warnings and forecasts: An effective warning and 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. These are typically taken to mean short-term warnings, such as those issued by the Bureau of Meteorology for the hazards that can literally be seen coming, such as cyclones, floods and severe storms. They may, however, also embrace the longer-term estimates of the 'hazardousness' of areas such as those contained in the earthquake hazard (acceleration coefficient) maps that accompany *AS1170.4-1993*, (Standards Australia, 1993) or by hazard maps specifically prepared for a city. They can both be significantly enhanced through the scenario analysis process.

Mitigation strategies and response options: Risk assessments are made so that strategies may be developed that ultimately will 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. Whilst the development and implementation of these strategies lie essentially outside the remit of the *Cities Project*, our experience in working with emergency managers and others to date suggests that amongst the most effective strategies are:

- a strong risk management culture;
- well maintained and appropriate information about risk, linked to comprehensive monitoring and warning systems;
- wide-spread and ongoing community awareness programs based on risk history, scenario analysis and an effective risk communication capability;
- emergency management plans, resources and training 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 levees and retrofit programs.

The key components of the *Cities Project's* understanding of the risk management process are illustrated in **Figure 1.2**.

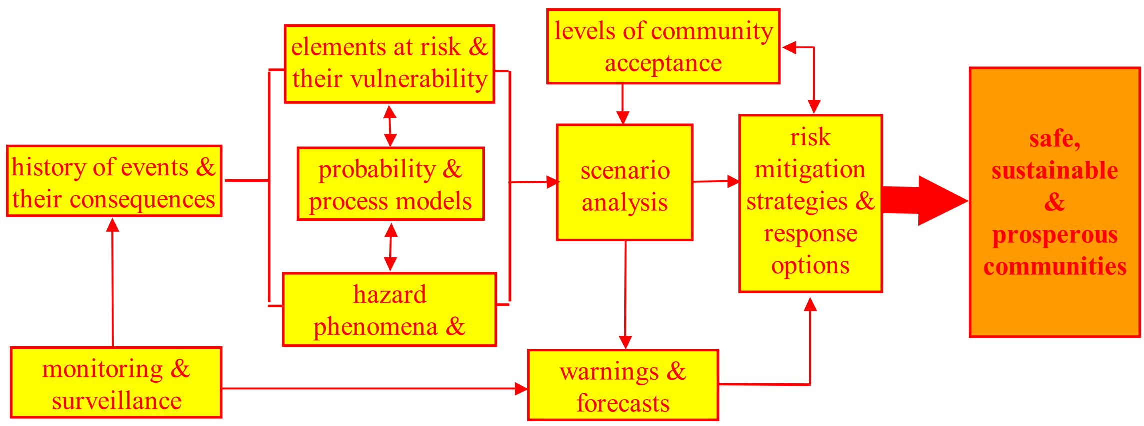

Figure 1.2: *Cities Project* understanding of the risk management process

The bottom line is that if we get all of this right, the outcome will be safer, more sustainable and more prosperous communities.

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 that it employs. Every effort has been made to ensure that the best available data have been used in the various analyses included in this report.

For the most part the results of modelling and other forms of analysis have been subjectively examined for 'reality' against the experience of the authors and a good number of external reviewers with appropriate local knowledge and experience.

The allocation of event probabilities is an area of particular uncertainty. For example, a common description of event probability is the 'return period' of a particular event, typically given in a form such as 'a one-in-one hundred year flood'. Not only are such figures typically based on less than 100 years of records, it has been widely reported that such an expression of probability is prone to be misinterpreted and misused. Description of an event as a 1:100 year event is frequently taken to indicate that there will not be another such event for another 100 years.

We prefer the terms 'average recurrence interval' (ARI) and 'annual exceedence probability' (AEP) which we consider less ambiguous. A typical ARI statement would be:

> *on the basis of the existing record, a flood measuring 11 m or more on the reference gauge occurs, on average, once every 25 years.*

A comparable AEP statement (for the same event) would be:

> *there is a 4% probability of a flood of 11 m or more occurring in any given year.*

Whilst such statements may be made about the probabilities of events occurring, they are frequently based on an incomplete and, often, statistically inadequate record. This is certainly the case in Cairns. The record of earthquakes, floods and cyclones extends over a little more than 100 years. That record is certainly incomplete. For the first 75 years or so of that time there was minimal instrumental measurement except for floods. Most of the smaller or more distant events went unreported. The recording of landslides has been even less complete.

The absence of what might be termed ‘absolute knowledge’ should not be seen as invalidating the assessments made. Rather, it should be seen as a challenge for the next iteration of the risk management process.