Developing an understanding of urban geohazard risk

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Presented at AGSO Cities Project Workshop,
Townsville, 8 July 1998

Introduction

This paper provides an overview of the geohazards risk assessment philosophy and practice that has evolved through the experience gained over the first two years of the Australian Geological Survey Organisation's (AGSO) *Cities Project*. It is offered as a contribution to the ongoing development of a national approach to the adaptation of *AS/NZS 4360:1995 Risk management* (Standards Australia, 1995) to the specific realm of emergency management.

The approach reported here is still somewhat provisional because we are still developing the information, techniques and tools needed to undertake a task as complex as assessing community risk to a multitude of hazards. There are several reasons for this 'provisional' status, not least of which is the need for our approach to be tested in the final step of the risk management process, namely the development of risk mitigation strategies and emergency response options at the community level. The first such application is currently being planned.

The Cities Project

The *Cities Project* was established in 1996 to undertake applied research directed towards the mitigation of the risks that are posed by a range of geohazards and faced by Australian urban communities. The ultimate objective of the project is to facilitate safe, sustainable and prosperous communities. To provide a realistic focus to this research, and to achieve early practical outcomes, the *Cities Project* is using a series of case studies based on Queensland centres to develop and test its science and techniques. Cairns is the first of these case studies, and the results of this study are used here to illustrate our approach.

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 is mainly on the potentially fatal acute geohazards such as earthquake, landslide and inundation, the importance of chronic, but economically significant, geohazards such as acid sulphate soil, coastal erosion, reactive clay and dry land salinity, is also recognised.

Such a broadly based program of research obviously demands a multi-disciplinary approach. To enable AGSO, which is a highly focused earth science research agency, 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 support 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 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 assessment approaches adopted under both the *Cities Project* and *TCCIP* are essentially identical, in spite of the different hazard phenomena being addressed.

Risk management

The concept of risk, and the practice of risk management, received a significant boost in Australia with publication of *AS/NZS 4360:1995*. This generic guide provides the philosophical framework within which *Cities Project* studies are developed. That process is outlined in *Figure 1*.

This paper deals largely with the risk identification, risk analysis and risk assessment stages of the process. The tasks of risk prioritisation and risk treatment are left to other stakeholders such as the Cairns City Council and the Queensland Government agencies that have that statutory responsibility.

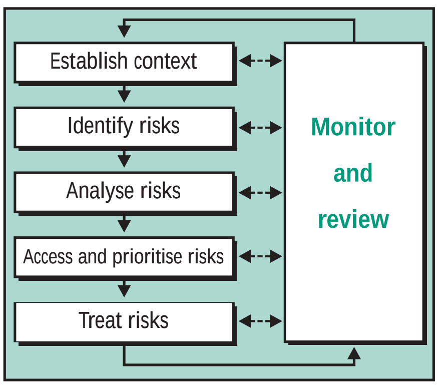

Figure 1: Risk management overview (Standards Australia, 1995, Fig 3.1)

What is Risk?

AS/NZS 4360:1995 (page 5) 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 thus be expressed simply in the following form:

$$Risk_{(Total)} = Hazard \times Vulnerability \times Elements\ at\ Risk$$

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 equally well 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 cost 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.*

It is clear that uncertainty is a key factor, indeed it can be argued that 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, therefore, clearly aimed at developing the best and most appropriate information with which to reduce that uncertainty.

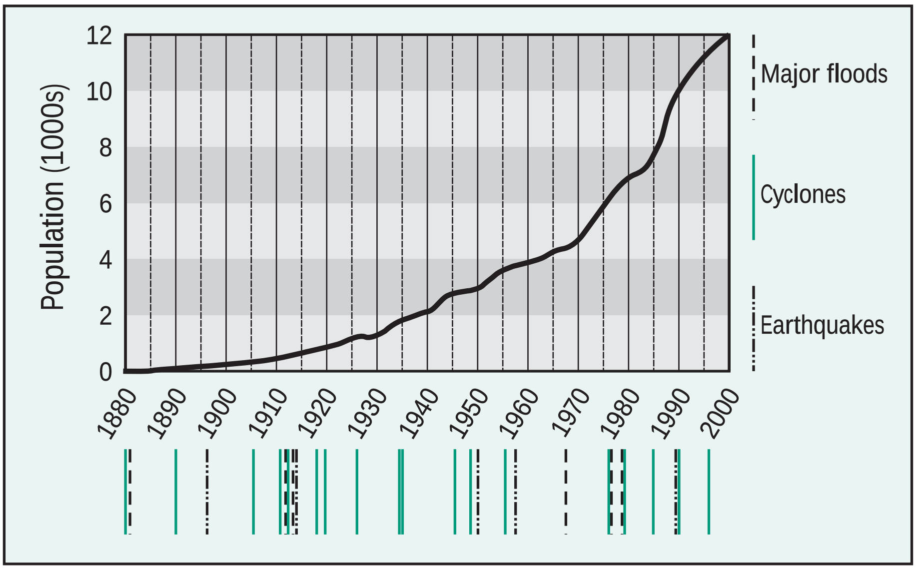

Figure 2: Cairns Risk History

Risk identification

A detailed understanding of what events have occurred in the past (including paleo 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, AGSO has developed catalogues on historic earthquakes, landslides and tsunami events, whilst the Bureau of Meteorology maintains comprehensive collections on severe weather events such as cyclones. The insurance industry maintains some data on the loss associated with such events. The material accumulated by the Newcastle Region Public Library on the 1989 earthquake in that city stands out as an exemplar of the type of comprehensive historical information resource that is needed to underpin community risk assessments. Whilst there is no comparable collection yet available for Cairns, *Figure 2* provides an overview of the 'risk history' of that city.

It is important to note that the earthquake of record occurred in 1896 (felt intensity of MMI 5+), the flood of record occurred in 1911 (15.39 metres gauge height) and the most significant cyclone impact on record was that of 1927 which put a storm tide of about 1 metre above high tide level through the town. In 1927 the population of Cairns was only 10% of its current level! The list does not include Australia's first BLEVE (boiling liquid expanding vapour explosion) accident that occurred in Cairns in 1987 or the numerous bushfires that have occurred in the area.

It is perhaps of little wonder that today there is a widespread belief in Cairns that they face little, if any, risk, from severe natural hazards. The myth of the 'glass wall' protection provided by the Great 'Barrier' Reef and the hinterland mountains unfortunately has great currency in Cairns.

Risk analysis

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 different 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 buildings, infrastructures and people. It draws on disciplines as diverse as geography, engineering, demography, economics and psychology. 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 very 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 census 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, 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, including materials of the walls and roof, the shape of the roof, the height of the floor above the surrounding ground, the number of stories and the age of the building, is required. These building characteristics contribute to the relative degree of vulnerability associated with exposure to a range of hazards, as shown in *Figure 3*. A database containing such details on more than 33,000[1] individual buildings in Cairns has been developed.

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 and the availability of vehicles, for example, have been acquired, as has the location and status of designated emergency shelters or safe havens. The detailed street network is held in topological form so that the neces-

[1] Collection of this data was made possible by a grant from the Australian Coordinating Committee for the International Decade for Natural Disaster Reduction in 1995.

sary route modelling analysis can be undertaken.

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 (see, for example, Granger, 1997).

The community is also dependent on the availability of food supplies, clothing, medical supplies and other personal items. Information is being 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 facilities such as hospitals, nursing homes, industries, commercial premises, agricultural land use, ambulance stations, fire stations, police stations and works such as 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 most of the 'warm and fuzzy' 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, meeting halls, sporting clubs and so on; however, the more meaningful measures relate specifically to the individuals, families and households that make up the community. Extensive use is being made of the detailed data from the 1996 National Census to flesh out our understanding of the socio-demographic and economic dimensions of vulnerability under both the 'security' and 'society' components.

Whilst other approaches to comprehensive risk assessment, such as *HAZUS* (NIBS, 1997), may segment the elements at risk differently, there is very close accord on their overall and individual significance.

Synthesis and modelling. Clearly, the range and variety of information needed to fuel a comprehensive risk analysis is enormous. Whilst there are many sources now available from which such information can be captured or derived, 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 (process, spatial and temporal) to fill the knowledge gaps. The behaviour of some hazards, such as bushfires and floods, have an established body of modelling research behind them, whilst others, such as cyclones and earthquakes, especially in intraplate areas such as Australia, 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 *predictions* of risk; rather we prefer to caveat them as providing nothing 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 85 to 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.

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	*****	****		****	***

Figure 3: Relative contribution of building characteristics to vulnerability

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 flood and 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 (an aspect about which *AS/NZS 4360:1995* is unfortunately silent) through its capacity to provide a visual representation of risk situations.

Risk assessment and prioritisation

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, typically extending from the relatively small and more frequently occurring events to those in the 'maximum probable' or 'maximum credible' range. *Figure 4*, for example, illustrates the cumulative range of risk associated with storm tide inundation scenarios for Cairns. This figure is similar to the 'risk curves' employed by the insurance industry and, indeed, the x-axis could be scaled to dollars of loss or potential fatalities, whilst the y-axis could be scaled (perhaps logarithmically) to event probability.

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 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, hence the need for a strong feedback mechanism between establishing acceptability and the formulation of risk mitigation and response strategies.

Perhaps the risk 'formula' could be better expressed as:

$$\text{Risk}_{(\text{Total})} = (\text{Hazard x Vulnerability x Elements at Risk})^{\text{Acceptability}}$$

to reflect the strong modifying influence of acceptability. Clearly, a key element in determining limits of acceptability rests with effective risk communication and public policy development.

The 'acceptability' factor is central to the process of risk prioritisation which 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

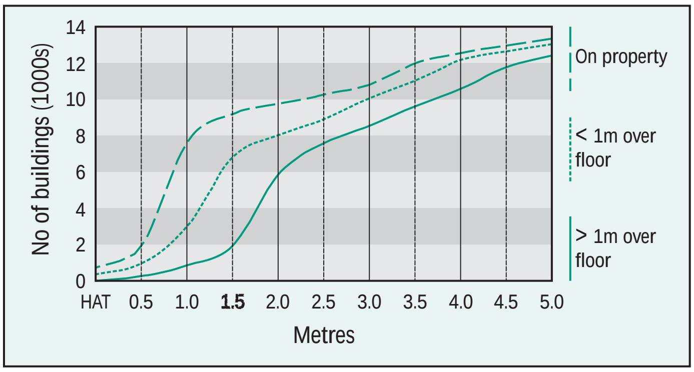

Figure 4: Number of buildings affected by different storm tide scenarios in Cairns with heights above highest astronomical tide (HAT).

those in which deep soft sediments are most likely to maximise earthquake impact. Conversely they 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 cyclone hazard with a 150-year return period is likely to be more severe than the impact of the shaking associated with a 150-year return period earthquake; but the maximum credible earthquake event may have a greater potential for catastrophe, than the maximum credible cyclone.

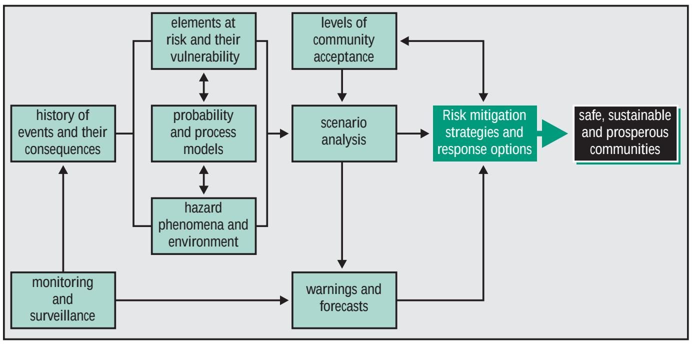

Figure 5: Cities Project understanding of the risk management process

Risk mitigation strategies

Whilst the *Cities Project* is concerned primarily with risk identification, analysis and assessment, it does have some linkage with elements of 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, the Bureau of Meteorology maintains some 45 weather radar sites, 246 automatic weather stations and 3,029 stream gauging stations, whilst AGSO has access to more than 150 seismographs across the country. 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. Whilst weather monitoring of Cairns is comprehensive and has reasonable historical depth, seismic monitoring coverage has until recently been relatively poor, with only the larger (and less frequent) events being measured by distant instruments.

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 mitigation. Whilst these warnings 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 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* 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:

- well maintained and appropriate information that is fundamental to risk assessment
- risk-based planning of settlement, development and key facilities (such as hospitals)
- protection plans for key facilities and lifelines
- cost-effective engineered defences such as levees and retrofit programs
- appropriate and enforced building and planning codes
- emergency management plans, resources and training based on risk assessments
- wide-spread and ongoing community awareness programs based on risk history, scenario analysis and an effective risk communication capability.

These components of the *Cities Project's* understanding of the risk management process are illustrated in *Figure 5*.

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

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Disaster events calendar

❖ 10–13 May 1999, Osaka, Japan

11th Congress of World Association for Disaster and Emergency Medicine (WADEM)

Contact: Secretariat of 11th Congress of WADEM, 1-1, Tsukumodai, Suita City, Osaka, Japan 565-0862; Tel: 81-6-6834-7364) Fax: 81-6-6872-1846
e-mail: wadem11@osk3.3wab.ne.jp

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www: http://www.adpc.ait.ac.th/Default.html

❖ 11–13 May 1999, Chicago, Illinois.

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