Chapter 3

GIS and Risk Management

3.1 Introduction

The application of GISs to natural hazard risk management is a relatively new and emerging science. It is likely, however, that GIS-based risk management will become a feature of state and local government natural hazard risk management procedures. In the context of formal risk management frameworks, such as the Australia and New Zealand Risk Management Standard (AS/NZS-4360 1995), the role of a GIS is yet to be examined in detail (for an Australian example see Granger 1997). This chapter introduces the emerging science of natural hazard risk management and examines the potential role of a GIS. There is scope for integrating a GIS with facets of natural hazard risk management. Terms including disaster, risk, vulnerability and hazard are used interchangeably and often ambiguously in natural hazards research. These terms are firstly defined and their relevance to natural hazard risk management is examined. The complexity associated with concepts of risk and the application of GIS to risk management is discussed by Rejeski (1993 p. 318) who notes that:

> Despite years of research, conferences and publications, those involved with risk assessment have yet to reach a consensus on many of these issues ... Those using GIS to model and estimate risks are pioneers in this landscape, caught between the subcultures of science, policy and the public. Navigation in and between these various cultural spaces presents some unique problems and challenges.

Handmer (1995) notes that there are ‘tensions in the fields of natural hazards and emergency management, between those approaching hazards from a technical perspective and those approaching hazards from institutional, political and social perspective’. Institutional, political and social GIS implementation issues including data custodianship, data sharing and legal liability issues are similarly relevant to disaster and risk management. Few examples in Chapter 2 accounted for these issues, which may be a greater barrier to successful GIS implementation than the technical hurdles. Drabek et al. (1994) note that there has been much less research on the political and administrative constraints that can keep public authorities form using technological solutions. Similar issues arise when GIS implementation issues are examined in Section 3.7.

3.2 Defining Disaster

Natural hazards, historically, have been perceived as random acts of nature, symbolised by extremes in physical processes. Disaster is a broad term that can include rapid-onset natural hazards including cyclones and earthquakes, or slower ‘creeping crisis’ such as drought, famine, or disease (De Paratesi 1989) It is difficult to define a disaster because it has varying magnitude, temporal and spatial dimension and varying social and economic consequences. In this thesis, disasters are synonymous with rapid onset natural hazards (i.e. storm surge). Blaikie et al. (1994) note that there is a danger in only associating disasters with uncommon and catastrophic events and separating them from social frameworks because too much emphasis is put on the physical agent itself. It has been suggested that the term ‘natural hazard’ is outdated and fails to acknowledge the importance of human factors in the disaster, or risk equation (Horlick-Jones 1993). Indeed the term ‘natural hazard’ does not reflect the diversity of disciplines working in disaster studies, including sociology, psychology, policy studies and risk management. In this thesis, disasters are discussed in relation to natural hazards because this is the common perception of disaster.

A disaster cannot occur if human development does not coincide with natural hazard impact zones including floodplains, earthquake source zones or low lying coastal land vulnerable to storm surge. This relationship can be summarised by the *Risk* = *f* (Hazard, Vulnerability, Elements at Risk) relationship. The terms risk and disaster refer to damage that can only exist in the presence of a vulnerable community (Hewitt 1983, Cannon 1994) . This philosophy of disaster challenges the historical emphasis on technological solutions to disaster reduction. Hewitt

(1983) terms this the *dominant* view, characterised by the notion that disaster is solely attributed to nature and that society can ultimately alter nature's course (see Rayner 1992 for a discussion of risk analysis and cultural theory). The dominant view focuses on technological solutions for disaster management, including engineering solutions, the study of hazard intensity, extent and frequency and hazard detection. Salter (1995) notes that the problem with treating disaster as only a physical event, with technological solutions, is that society limits the number of intervention options available. *Vulnerability* is defined by Blakie et. al. (1994 p. 9) as :

> ...the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard. It involves a combination of factors that determine the degree to which someone's life and livelihood is put at risk by a discrete and identifiable event in nature or society.

Horlick-Jones (1993) identifies key themes that have arisen from vulnerability studies in natural hazards research including those listed below.

- Location - the geographical proximity to the hazard in question.
- Livelihood/Circumstances - the position and status in society, which in turn is related to wealth, class, gender, ethnicity, health and other factors.
- Self protection - capacity of the population to protect itself from harm, access to materials, knowledge and information.
- Social protection - the extent to which the society in which the population is embedded can provide mitigation measures, including resources and technical knowledge.

The theoretical basis for vulnerability focused disaster management has existed in the academic literature for some 50 years. For example, the pioneering work of White (1945) and later work of Burton et al. (1978) and Hewitt (1971, 1983) has established the foundation for a vulnerability approach to disaster management and prevention. Hewitt's (1983) thesis argues that the technocentric focus reflects the fact that 'hazard' studies are rarely seen as research in their own right but as an application and '...the expertise, therefore, is invariably that of a discipline such as seismology or cognitive psychology, or a technique, say, statistics or remote sensing. The research is essentially an empirical study of questions specified by an agency's responsibility...'

Similarly, GIS applications discussed in Chapter 2 are fundamentally technical solutions for disaster reduction.

In the context of storm surge disaster reduction in Australia, the technocentric approach is well represented. Most research initiatives associated with the Tropical Cyclone Coastal Impacts Project (TCCIP) have a meteorological focus (TCCIP 1997) . A 1956 conference focusing on cyclone hazard in Australia contained 37 research papers, all of which were technical, detailing genesis, methods of detection and forecasting (Bureau of Meteorology 1956) . Reflecting the shift from the dominant view, the recent Seminar on Tropical Cyclones and Floods (Bureau of Meteorology 1995) contained 20 research papers, of which only six were technical. The remainder dealt with vulnerability issues including planning, community preparedness and the psychological implications of disaster. The focus on technological solutions has not served society well when risk and disaster reduction is assessed. Even with better warning systems, a clearer understanding of earthquake behaviour and improved cyclone tracking, losses associated with natural hazards are greater than they have ever been (see Chapter 1.2.3). The adoption of a risk management framework among Australian natural hazard risk management stakeholders is a first step in formalising the importance of social vulnerability issues. Section 3.3 examines risk in further detail and introduces the risk management standard.

3.2.1 GIS and the Vulnerability Paradigm

A GIS is fundamentally a technocentric tool for disaster reduction. Most examples from Chapter 2 adapted a GIS for hazard assessment, hazard mapping and risk communication using cartography. A GIS implementation for natural hazard disaster reduction should also have social and vulnerability considerations. The spatial data itself will determine whether the methodology is strictly technocentric, or whether it accounts for vulnerability. Secondly, non-technical, GIS implementation issues such as data custodianship, access to data, user-needs assessments and legal liability concerns may be a greater barrier to successful natural hazard risk reduction than technical issues of hardware, software and data (see Section 3.7 for a detailed discussion).

GIS literature suggests that, historically, the fundamental challenges are software, hardware, data capture and hazard modelling. These findings are discussed in further detail in Chapter 9 which outlines the results of a user survey of risk managers in Cairns and Mackay. As with other aspects of disaster research, a key limitation of applying a GIS to vulnerability analysis is the challenge of adequately representing human vulnerability constructs within a GIS. Hewitt (1983) would argue that this would be a futile exercise, not unlike an attempt to model human behaviour mathematically and akin to 'the mumbo-jumbo of numerologists'. Two workshops that examined vulnerability issues and attempted to develop an assessment procedure were held in 1996 at the Australian Disaster Management College at Mt. Macedon, Victoria. Much of the workshop was spent defining the term 'vulnerability', let alone developing a practical assessment procedure, illustrating the challenges associated with introducing vulnerability paradigms into GIS-based risk management. This situation is not unique and most examples in disaster and hazards literature examine issues and challenges of vulnerability analysis, rather than providing solutions (see Alley 1993).

Disaster management specialists consider vulnerability analysis to be a major aspect of disaster preparedness (de Paratesi 1989). This thesis provides a relatively simplistic treatment of vulnerability by only including commercial and residential buildings and road networks as components of the risk model. Preliminary user surveys conducted in Mackay noted that this was the primary need for emergency management (see Chapter 8.4). Therefore, the thesis contends that vulnerability components of disaster discussed by Hewitt (1983), Blaikie et al. (1994) and Burton and Kates (1964) exist at different administrative scales than emergency management preparedness and response functions.

The methodology developed in this thesis aims to address the decision-making needs of emergency managers, who are a group with a well defined area of responsibility. Although treatment of vulnerability in this thesis is relatively cursory, it is still valuable for its spatial coverage, spatial detail and accuracy. The thesis presents a fundamentally technocentric methodology for disaster reduction, which includes risk analysis, risk mapping and risk communication. The implementation of a GIS, however attempts to account for the social constructs of disaster by:

- Ensuring the language of the thesis avoids a technical emphasis.
- Including vulnerability in the model (buildings/roads as surrogates for population).
- Modelling and visualising the consequences of uncertainty in risk model results.

- Assessing user perceptions of risk in the context of improved decision-making.
- Examining non-technical facets of GIS implementation (political & social factors).

The concept of vulnerability is complex, with a range of definitions and interpretations. In the context of a GIS and spatial analysis, the intangible facets of vulnerability do not lend themselves well to spatial modelling, or may not even have an observable spatial component. Acknowledging this limitation should be a first step when a GIS is integrated with risk management.

3.3 Defining Risk

Risk is a term used in natural hazards research with many definitions. Whyte and Burton (1980) note that *risk* has two distinct meanings. It is used to describe the physical presence of a hazard, such as the occurrence of tropical cyclones in Northern Australia. Alternatively, risk is the probability of a particular event occurring, such as a flood recurrence interval and spatial extent. This second interpretation is a quantifiable measure of risk. Definitions from hazards literature illustrate the diversity of risk definitions possible:

- Risk is a concept used to give meaning to 'things, forces or circumstances' that pose a danger...typically stated in terms of likelihood of loss (from a hazard) (Salter 1998) .
- The chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood (AS/NZS 4360:1997).
- Risk can be considered as the possibility of suffering harm from a hazard (Eastman et al. 1997) .
- Risk deals with the probability of an event causing a potentially undesirable effect (Beer and Ziolkowski 1995) .
- The concept of risk implies the possibility of suffering a loss. The size and occurrence of the loss, however, is uncertain (Burby 1991) .
- Where factors and processes are sufficiently measurable for believable probability distributions to be assigned to the range of possible outcomes (Dovers 1995) .

- The potential for accidental incapacitation or casualty, the chance of dying immediately or in the future as a result of exposure to any one of the listed activities or substances (Lafond and Gosselin 1994) .

- The potential for realization of unwanted, adverse consequences; estimation of risk is usually based on the expected results of the conditional probability of the occurrence of an event multiplied by the consequence of the event, given that it has occurred (USACE 1995) .

- 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 (Fournier d'Albe 1986).

Definitions commonly associate risk with negative consequences and risk management seeks to ameliorate these. People's perceptions of risk events are rarely close to the objective likelihood of the occurrence of that event (Lafond and Gosselin 1994, EPA 1997, Golledge and Stimson 1997). Definitions of risk, with their subtle variations, contain a common interpretation of risk: *Risk is the likelihood of something happening which affects objectives*. Applying a natural hazard interpretation of risk, the term 'objective' usually includes the goals listed below.

- Minimising the loss of life and injury to persons.
- Minimising the loss to property and infrastructure.
- Reducing the damage to social, political and economic structures.
- Restoring society to its 'normal' state.

The Australian/New Zealand Risk Management Standard 4360 (1995) is in the process of adoption by emergency management stakeholders in Australia. The Standard attempts to shift the focus of emergency management from its traditional technical focus, to a more holistic risk management model. Natural hazard risk is commonly expressed as a measure of likelihood and consequence. Once the existence of a risk has been established in a geographical area, a description of the risk can be provided by considering likelihood and consequences. Likelihood measures can be quantitative, qualitative and comparative. The likelihood of natural hazard risk may be expressed as:

- A bushfire intensity likely to occur when a given fuel-load is exceeded is high.
- The probability of a Category two cyclone crossing Brisbane is considered low.
- A two metre storm surge has a 1% chance of occurring in any given year in Cairns.
- The likelihood of sea level rise is greater with an increase in global warming.
- Probability of an earthquake greater than Mercali intensity IV in Newcastle is high.
- The likelihood of riverine flooding in Melbourne is less than in Brisbane.

And the respective consequences may include:

- The destruction of buildings is highly likely and possibility of deaths.
- Minimal property damage is expected because winds speeds are below a threshold.
- The flooding of buildings, chance of death from drowning and economic losses.
- The loss of urbanised coastal land may result in large relocation costs.
- The loss of buildings and destruction of utility and communication networks.
- Consequences would be minimal because excellent floodplain management exists.

From a local government perspective, the greatest advantage in adopting a risk management model is that it establishes an integrative framework for disaster reduction. It aims to include natural hazard risk management into the broader gamut of local government responsibility. Secondly, it encourages a temporally ongoing treatment of risk rather than a series of discrete steps, characterised by the PPRR model. As Green (1994) notes, 'since the process of hazard management is a sequence over time, it makes logical sense to start disaster management at the beginning rather than at the end. The need to plan to manage disasters is a sign that hazard management has been ineffective'. The following section examines the AS/NZS 4360 applied to natural hazard risk management, with specific attention to how a GIS can be integrated with various stages of the process.

3.4 Natural Hazard Risk Management

A distinction exists between risk management and risk assessment. Risk assessment is the quantitative stage, where potential negative and positive consequences are examined systematically (Lind 1991). In such a model, risk management treats the risk assessment phase as one input and can include social, economic and political considerations. Risk management is the entire process, from risk identification, through to communication and decision-making. Risk management is the 'systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, treating and monitoring risk' (AS/NZS 4360:1995). Similarly, Whyte and Burton (1980) view the process of risk management as a series of steps, applied to identify a path of least resistance between social benefit and environmental risk. They define risk management as a '...balancing or trading-off process in which various combinations of risks are compared and evaluated against particular social or economic gains' (Whyte and Burton 1980). Lind (1991) defines the risk management process as a sequence of steps of evaluation and decision-making where, for the outcome to be successful, all decisions should involve public consultation and should be supported by reliable and appropriate methodologies, by data that are open to scrutiny and by judgements that clearly indicate the assumptions made (Chapters 5 and 6 address these issues from a GIS and spatial modelling perspective).

Natural hazard risk management introduces terms that are used interchangeably and ambiguously. Terms include *risk assessment, risk management, risk evaluation* and *risk estimation*. American English and Australian English reverse the meaning of the terms risk analysis and risk assessment (Beer and Ziolkowski 1995) In the U.S., *risk assessment* refers to the quantitative stage and *risk analysis* encompasses the individual components including risk assessment, risk management, risk perception and risk communication. In Australia, the quantitative component is termed *risk analysis* and *risk assessment* is the overall process (Beer and Ziolkowski 1995). Kates (1978) defines risk assessment as 'an appraisal of both the kinds and degrees of threat posed by an environmental hazards.' The Australian/New Zealand Risk Management Standard 4360 (1995 p. 5) defines risk assessment as:

> The process used to determine risk management properties by evaluation and comparing the level of risk against predetermined standards, target risk levels or other criteria *and risk analysis is defined as* a systematic use of available information to determine how often specified events may occur and the magnitude of their likely consequences.

3.5 Australian/New Zealand Risk Management Standard

The Australian/New Zealand Risk Management Standard AS/NZS-4360 (1995) (hereafter referred to as the Standard) '...provides a generic guide for the establishment and implementation of the risk management process involving the identification, analysis, assessment, treatment and ongoing monitoring of risks'. It has been developed to define and encourage formal risk management practices in such diverse fields as assets management, fire detection/fire prevention, fraud prevention, financial investment, occupational health and safety and natural hazard risk management. The Standard is composed of five major components (Figure 3.1): establishing the context, risk identification, risk analysis, risk assessment and risk treatment. The following section examines each stage of the Standard and the potential role of a GIS. Salter (1998) notes that advantages of adopting a risk management framework for emergency management include:

- It is a formalised, systematic analysis and decision-making process.
- It is being widely used, thereby providing a common language and process across all organisations, facilitating both promotion and integration.

Figure 3.1 Risk Management Process

3.5.1 Establishing the Context

Establishing the context focuses on institutional issues surrounding the organisation implementing the Standard. 'The step establishes the strategic, organisational and risk management context in which the rest of the process will take place. Criteria against which risk will be assessed are established and the structure of the analysis is defined' (AS/NZ 4360:1997). Context includes issues such as the legislation under which the organisation functions, the natural hazards the organisation is responsible for or its links to other organisations with similar objectives. From a GIS implementation perspective, this will include non-technocratic implementation issues that are rarely examined in the GIS literature, yet are critical for the successful integration of GIS. Section 3.7 examines these issues in more detail. This stage is important because it identifies the aims and objectives as well as the GIS and spatial analysis limitations of the project. Some key issues are listed below.

- Scoping existing GIS and risk management case studies locally and internationally.
- Determining whether existing GIS capabilities are available in the organisation.
    - Software
    - Hardware
    - Experienced personnel and training
- Assessing non-technocratic GIS implementation issues.
    - User-needs assessments
    - Cost-benefit analysis
    - System specifications and bench-marking
    - Legal liability issues
- Spatial data issues.
    - Determining the spatial extent of the risk study area
    - Determining the spatial data themes required to meet objectives
    - Determining current spatial data holdings of the agency
    - Assessing fitness-of-use of existing spatial data (data currency)
    - Consulting spatial data directories for existing databases
    - Establishing data sharing agreements with stakeholders

- Establishing metadata requirements
- Access to historical hazard zonations

• Spatial risk modelling issues.

- Assessing whether the complexity of the hazard phenomenon is amenable to spatial representation and modelling
- Determining the level of accuracy expected from the risk assessment
- Determining the spatial data model for risk analysis (raster/vector) or whether topology is required (network analysis)
- Determining the geographic projection appropriate for risk analysis
- Determining the level of spatial uncertainty that can be tolerated

• GIS-based risk communication objectives.

- Identifying the intended audience
- Establishing risk communication techniques and objectives

3.5.2 Risk Identification

Risk identification seeks to identify whether a hazard exists and, if so, to define its characteristics (Whyte and Burton 1980). Risk identification considers the complex interaction of socially constructed environments (vulnerability) and natural systems (hazards). For engineering-based risk identification such as power station failure, this is relatively easy because details of the construction process and infrastructure dependencies are planned and quantifiable. Kates (1978) notes that for natural hazards risk management, it may take major scientific advances to identify a threat. For example, where recurrence intervals for earthquake hazards are unknown, identifying the potential hazard may require detailed analysis of regolith structure and ground shaking potential. Commonly, risk identification focuses on a single hazard rather than applying a multi-hazard framework (Burby 1991). This is changing as society recognises the importance of multi-hazard treatments of risk. Three aspects of the physical hazard are identified, including the region it affects, its potential magnitude and its recurrence interval. Secondly, risk identification attempts to determine the elements at risk (vulnerability). Examples of GIS applications for risk identification are common, particularly for mapping credible sources of risk. GISs have been less successful at mapping credible elements at risk (vulnerability). From a GIS perspective, this stage of the Standard is an inventorying stage and may include the following:

- Mapping hazard zonations.
    - GIS-based hazard models (landslide susceptibility)
    - Spatially explicit numeric models (SLOSH, ALOHA and MEOWS for surge)
    - Historical hazard risk maps
    - Real time mapping from remotely sensed imagery (bushfires, floods, storms)
- Mapping hazard magnitudes.
- Mapping recurrence intervals (spatio-temporal modelling).
- Mapping hazard inter-dependencies.
- Mapping spatial elements at risk.
    - Engineering lifelines (utility networks, roads, communication networks etc.)
    - Built environment including residential and commercial buildings
    - Natural environment - biodiversity, ecological indicators, species maps
    - Human component - community profiles such as age, sex, ethnicity

The risk management process notes that, in order to establish the context, it is necessary to move forward and *Develop Criteria* (Figure 3.1). There are other elements of risk identification that do not lend themselves to spatial representation including institutional structures and political environments. Acknowledging this limitation is critical to ensure that the objectives of GIS implementation do not exceed the practical limitations of a GIS.

3.5.3 Risk Analysis

AS/NZS 4360 notes that ‘risk is analysed by combining estimates of likelihood and consequences in the context of existing control measures. The objectives of analysis are to separate the minor acceptable risks from the major risks and to provide data to assist in the treatment of risks’. Risk analysis is therefore the integrative stage where vulnerability and natural hazard are combined to obtain an estimate of risk. By its nature, a GIS-based risk analysis will commonly be quantitative, although this is not an explicit requirement. Aspatial risk analysis techniques may include *cost-effectiveness analysis* (Lind 1991), *structured interviews* (Salter 1998) and *sensitivity analysis* (EPA 1997). From a spatial analysis perspective, risk analysis is a challenging component of risk management because integrative spatial modelling techniques must be developed. The risk analysis phase also introduces uncertainty because 'wherever possible the confidence placed on estimates of levels of risk should be included' (AS/NZS 1995, see also Chapter 6). The Standard notes that the quality of a risk analysis depends on the accuracy and completeness of the numerical values used. It would be a challenge to list all GIS techniques for risk analysis and many of these have been discussed in Chapter 2. Some brief examples are shown to illustrate the role of GIS for risk analysis (for more detailed treatment of GIS-based risk analysis see Newkirk 1993b):

- Spatial modelling techniques.
  - Spatial overlay of credible sources of risk with elements at risk including spatial intersections, unions, buffers
  - Use of raster Map Algebra for spatial overlay of hazard and vulnerability
  - Integration of time-series data
  - Interpolation of discrete data to generate continuous surfaces
  - Topological network analysis for evacuation planning

- Sensitivity analysis.
  - A range of credible sources of risk and integrate this with elements of risk
  - To assess importance of input variables and model sensitivity on risk results

- Integration of GIS with external analytic models such as storm surge models.

- Integration of GIS with statistical models external to the GIS.

- Assessing uncertainty in risk management.
  - Parameter uncertainty
  - Spatial uncertainty
  - Attribute uncertainty
  - Model uncertainty

- Deriving secondary variables (slope, aspect) from primary data (DEMs) to identify other sources of risk and to develop risk decision rules.

- Archiving results of risk analyses using relational database management systems.

- Developing evacuation maps based on hazard and vulnerability coincidence.

• 3-Dimensional modelling.

3.5.4 Risk Assessment

'Risk assessment involves comparing the level of risk found during the analysis process with previously established risk criteria, and deciding whether risks can be accepted' (AS/NZS 1995). A feature of risk assessment is risk communication to decision-makers, to relevant agencies and stakeholders and to the public. This phase of risk management is a decision-making phase and can benefit from GIS integration. Risk communication is a key component of risk assessment because it can facilitate objective dialogue and encourage risk reduction (risk treatment). Risk communication is facilitated by cartographic representation, 3-Dimensional visualisation, animations of risk, decision support systems and other techniques which communicate spatial pattern, magnitude and relationships. This is evidenced in Queensland, where GISs applied to storm surge risk mapping have been an impetus for changing government and community risk perceptions and therefore risk preparedness (see Chapter 8).

The communication capabilities of a GIS may help risk managers identify spatial dependencies inherent in risk. Spatial patterns of risk may help identify causal factors that are critical for the risk treatment phase. Without a GIS, hazard and vulnerability interdependencies may remain unknown and causal relationships obscured. Another component of risk communication is social equity. The Standard should ensure that equitable access to GIS results exists for stakeholders, because this may add another dimension of vulnerability to the population. Added to this, risk managers and GIS practitioners need to ensure that objectives of clarity and honesty are observed (Rejeski 1993). Chapter 8 provides a user perception study of the results of risk models within the context of improved decision utility.

3.5.5 Risk Treatment

The Standard notes that risk treatment involves identifying the range of options for treating risk, evaluating those options, preparing risk treatment plans and implementing them. Treatment options for natural hazard risk commonly fall into one of the prevention, preparedness, response and recovery categories (PPRR). The literature review presented in Chapter 2 provides many examples of GIS applications for each risk treatment option. Most examples focused on response activities because this reflects the dominant approach for managing natural hazards, globally and in Australia. Prevention and preparedness activities were under-represented, owing to the broader neglect of these treatment options, rather than for any technical or data limitations inherent in a GIS.

3.6 Uncertainty

Natural hazard risk management attempts to remove uncertainty for improved decision-making, and ultimately for risk reduction. The Committee on Flood Control Alternatives in the American River Basin (USACE 1995) notes '...that the term uncertainty has been given a broad and sometimes conflicting range of meanings...guidelines indicate that actual uncertain planning situations are located on a continuum between situations of known risk...and situations characterized by uncertainty.' Uncertainty is a recurring theme that arises in discussions of natural hazard risk. The inclusion of uncertainty is central to the notion of risk (see also Handmer 1995, Rejeski 1993, Newkirk 1993b, Salter 1998, Wynne 1987). The National Research Councils Panel on Earthquake Loss Estimation Methodology (in Burby 1991 p. 130) highlights the importance of uncertainty for risk management:

> No loss estimation prepared today, or in the foreseeable future, can be completely accurate. There are major gaps in our knowledge, both as to the time of occurrence, magnitude, and location of future earthquakes and as to the manner in which the ground and structures will respond to earthquakes. Any loss estimation inherently involves uncertainties. Despite their limitations, loss studies that are properly conducted and used with an understanding of the method's limitations can be of great value.

Epstein et al. (1998) note that uncertainty is reduced by acquiring more information and/or improving the quality of the information. Acknowledging, accounting for and communicating uncertainty is a primary issue confronted in natural hazard risk management. Although uncertainty is not necessarily quantifiable (Dovers 1995), Chapter 5 examines error assessment and error reduction techniques for DEMs, and introduces the relevance of uncertainty for storm surge risk modelling. Chapter 6 examines uncertainty in further detail, and assesses two techniques for communicating the consequences of spatial uncertainty for risk management in a GIS.

3.7 GIS Implementation Issues for Risk Management

3.7.1 Introduction

Historically, research on the role of a GIS for natural hazards risk management has focused on technical issues. This includes spatial data requirements, the modelling of natural hazard processes in a GIS environment (risk identification) and hardware and software specifications. This thesis contends that major barriers for successful implementation of a GIS for natural hazard risk management are non-technical. These constraints are similar to those that have existed within the natural hazards emergency management community. Namely, a focus on technological solutions rather than the treatment of vulnerability. Institutional constraints for GIS implementation are far ranging, and encompass social, political and technical issues. Although technical issues such as data are discussed, it is problems surrounding their implementation that are critical. Each of these issues is a component of the risk management process. Non-technical constraints for GIS implementation include those listed below.

- Metadata (information about data) standards
- Data custodianship (ownership and responsibility)
- User-needs assessments
- Cost-benefit analysis
- Legal liability
- Cognitive and user interaction issues
- Spatial data sharing agreements
- Establishing spatial data clearinghouses and directories
- Political impediments at various scales
- Social constraints including access to spatial information (social equity)

There is a dearth of literature that addresses these issues, let alone any literature specific to natural hazard risk management. The risk and GIS community has traditionally focused on modelling hazards, rather than addressing implementation issues. Organisations faced with long term implementation issues including consulting companies or local governments, traditionally do not publish in the public domain. Risk managers have few guidelines available to them when assessing the utility of implementing a GIS for risk management and decision support. The burgeoning marketing campaigns by companies eager to sell a GIS as a solution to all risk management problems adds further complexity. The reality, however, is that the current generation of commercial GISs are probably not suited to the wide range of tasks that risk management requires (Rejeski 1993). For instance, the exaggerated claims of Morentz and Griffith (1994 p. 9) in their paper on emergency planning and GISs, do little to encourage a cautious and planned route for GIS implementation.

> A GIS is a multipurpose analytical tool that performs a seemingly endless variety of calculations to describe geographic features of the earth...it will do just about any analysis conceivable... any emergency management office would improve its analytical capabilities with a GIS.

An agency's or community's access to spatial data is a potential source of vulnerability and social disadvantage. Access to spatial data is also a barrier to successful GIS implementation. Newkirk (1993a) notes that '... a new risk GIS would be based on accessing and sharing data across well defined networks. Development must begin with the definition of standards for data transfer, granting access, sharing resources.' These facets of GIS implementation are discussed with reference to natural hazard risk management in Australia. The discussion introduces the emerging issues to natural hazard risk managers who may be anticipating the use of GIS for decision-making. It provides a precautionary outlook for risk managers charged with integrating GIS into their work-place. The discussion focuses on the Australian context, although a number of North American examples are provided because the issues are fundamentally the same.

3.7.2 Illustrative Scenario

To illustrate the practical GIS implementation issues, a scenario relevant to natural hazard risk management is provided. The scenario is modified from one presented by Onsrud (1996) in his discussion of unethical conduct in the use of GIS.

> A Queensland local council developed a city wide GIS financed by taxpayers. The council has been using the system for street and utility maintenance, zoning, tax assessment, planning, inventory of city facilities and for other land use analysis. The council soon discovered that the database was useful for a number of commercial uses. Although the GIS was originally justified on cost savings to the city, through improved efficiency, the council is now charging residents fees for on-line access to the GIS and is also selling spatial data products from the database to recover the costs of acquisition, maintenance, upgrades and expansion.

One of its major customers is a multinational insurance company. The insurance company is using the data to establish insurance premiums for building loss and damage from flood inundation. The fees are generating a substantial income that far exceeds the original costs and the continuing expenses of the GIS. The commercial agreement with the insurance company ensures that the company will receive annual updates as new areas are subdivided. Subdivision plans submitted by surveyors have progressively been incorporated into the GIS by manual digitising. Although the council transcribed the property boundaries from the original plans correctly, metadata items, such as the dates of field surveys, map legends, and notes outlining the accuracy standards that the survey work was intended to meet, have not been incorporated into the GIS.

Surveyors argue that the maps and plans represent professional opinions of the surveyors (not just factual information) and the council should have sought their permission prior to converting the information from the paper maps. The surveyors argue that their liability exposure to third party users is now likely to be greater as a result of a council's GIS development and data dissemination to insurance companies. They argue that they should be receiving a substantial percentage of all GIS fees being collected by the city. On the other hand, the council believes all the data copied was factual and they feel the general public should gain the full benefit of the fees they are collecting. The council refuses to pass any percentage of the fees to the surveyors.

This complex, yet feasible, scenario raises GIS implementation issues including:

- Data ownership and custodianship
- Metadata standards
- Legal liability for decisions based on spatial data
- Public access to spatial data or social equity

3.7.3 Historical Context

Impediments to the successful implementation of a GIS for natural hazard risk management are also common within other facets of natural hazard risk management. For example, the successful establishment of natural hazard warning systems, landuse mitigation strategies and the establishment of evacuation routes, can be hindered by the same social, political and institutional constraints (see Hewitt and Burton 1971, Kates 1978, Blaikie et al. 1994, Salter 1995). A similar bias has occurred within the GIS research community with its focus on technology. This historical technical focus can be attributed to two major factors:

- Technical constraints needed to be overcome before GIS could be integrated into practical decision-making and now these issues are beginning to emerge.
- The traditional background of the disciplines involved in the early stages of GIS development (i.e. quantitative geography, cartography, surveying, computer programming) is reflected in the research foci.

The recent use of GIS for risk management can be attributed to factors including:

- Decreasing costs of computer hardware
- Decreasing costs of GIS software
- Availability of GISs on desktop computers and recently on the WWW
- Integration of GIS functionality into other software (i.e. spreadsheets, relational databases)
- Availability of a diverse range of spatial data commercially (census data, national road centre-lines, DEMs, natural environment data)

The U.S. National Centre for Geographic Information and Analysis (NCGIA) provides an important indicator of emerging trends in GIS research. Recent NCGIA initiatives highlight the importance of human factors in the GIS implementation process. NCGIA Initiative 19 is titled 'GIS and society: The social implications of how people, space, and environment are represented in GIS' (see http://www.geo.wvu.edu/i19/). A case study developed under Initiative 19 is particularly relevant to natural hazard risk management. The project is titled 'Local knowledge, multiple realities and the production of geographic information: A case study of the Kanawha Valley, West Virginia'. It examines how public access to geographic information impacts on the perception and management of environmental and technological risk. The research focuses on '...the extent to which geographic information has been made available, is available, could be made available to the citizens and community groups in the region, and how this flow and control of information has affected the nature of local, community, and plant struggles over environmental regulation'.

Non-technocratic implementation issues relevant to GIS are widespread and continue to expand as GISs are adopted by different interest groups. For example, legal liability issues associated with GIS modelling results have not been tested, but will become more common as GIS-based modelling becomes more widespread. For example, where does legal liability lie when decisions are based on false assumptions of spatial data accuracy ? Epstein et al. (1998) note that 'The issues of error and uncertainty in GIS...has received growing attention from all sectors of the industry with the realization that there is now considerable potential for litigation and loss of personal and agency integrity arising from errors in geographical databases'. This discussion presents key implementation issues which are not technological, yet can act as significant impediments to the successful use of a GIS for risk management. The list of issues is not exhaustive, but rather presents more common factors risk managers should be aware of including spatial metadata, data sharing and custodianship, user-needs assessment and legal-liability.

3.7.4 Spatial Metadata

Metadata are information about data. Metadata describe aspects of the data including accuracy, scale, date of capture, lineage, custodianship, spatial extent and logical consistency, to name a few core elements. Since a fundamental objective of risk management is to reduce uncertainty, metadata is a key component of spatial databases. The fact that metadata issues have received widespread attention in the last few years may indicate two non-mutually exclusive things (ANZLIC 1996) .

- Metadata is an issue that has been significantly neglected in the GIS community.
- Metadata is critical to the successful integration and dissemination of spatial data for decision support including natural hazard risk management.

A feature of a GIS is that it allows primary data to be converted into new, or secondary, data types. Slope surfaces, for example, are derived from digital elevation models, which are obtained from topographic contour and spot elevations. This GIS functionality introduces uncertainties regarding the *lineage* of the derived data. Lineage describes the history of spatial data including the processes and input data used to derive the current version. Without metadata, these uncertainties make determining the fitness-of-use of spatial data difficult. Measures of accuracy, precision and timeliness that are published with paper maps can be lost through the data conversion and spatial analysis. Metadata standards also receive attention as the modelling phase of GIS establishes itself. The initial phase of GIS implementation within local government has been characterised by data conversion, such as the digitising of paper maps. This era has had limited need for metadata, because metadata were readily available from the paper source maps. An impetus for the development of metadata standards has been the commercialisation, and consequent dissemination, of spatial data. This *value-added* phase has led spatial data custodians to re-sell spatial data, and there is an expectation from customers for detailed documentation in the form of metadata.

Recently, spatial data are also being developed specifically for digital purposes. For example, global positioning systems (GPS) data remains in a digital format, from its initial capture, to its use for GIS-based modelling. Because the data remains digital, metadata may be lacking. This is an issue when GPS points are used to create a DEM, and any knowledge of their existence, accuracy, currency and precision may be lost. To address these issues, the Australian New Zealand Land Information Council (ANZLIC) has drafted metadata guidelines that provide a standard for spatial metadata (http://www.anzlic.org.au/metaelem.html).

The establishment of spatial data *Clearinghouses* (or spatial data directories) has also driven the development, and encouraged the adoption, of metadata standards. The Clearinghouse concept is a U.S. term that describes a distributed network of spatial data which conforms to particular standards. The Clearinghouse is usually Internet-based and can be searched by spatial extent or by the theme of spatial data. The objective of the Clearinghouse is to avoid duplication of the data and to promote effective and economical management of spatial data resources nationally. The Clearinghouse contains only metadata and users would contact the custodians to obtain data. ANZLIC metadata guidelines summarise the importance of creating and distributing metadata for spatial data (a first stage of the risk management process). The commercialisation of spatial data has also fuelled the need for metadata. National land management agencies, local governments and private companies who capture and utilise spatial data have seen an expansion in the need for their databases for purposes ancillary to those for which they were designed. For natural hazard risk management, metadata guidelines may include the following themes.

- Detailed information about data collection methods, integration, and analysis applied to various components of source data to support the preparation of a scientific report.

- Information about the accuracy of source datasets, processing history, and archival procedures to effectively manage and utilise data within custodianship organisations.
- Information about projection specifications, scale, and a data dictionary to accompany data transfers to other organisations.
- Adequate descriptions of the content, quality and geographic extent of datasets so potential users of existing data can assess its suitability for other purposes.
- Summary descriptions of content and quality as well as contact information for inclusion in directory systems.

3.7.5 Metadata Case Studies for Natural Hazard Risk Management

The U.S. Federal Emergency Management Agency (FEMA) is charged with creating, storing, and disseminating spatial data for hazard risk management. Natural hazard focused, national scale spatial data custodians are rare in Australia. State agencies such as the Country Fire Authority in Victoria, and the Department of Emergency Services in Queensland fulfil a similar role. The Australian Geological Survey Organisation and Bureau of Meteorology maintain some national-scale data suitable for hazard risk management. FEMA flood data (FEMA 1996) comes with metadata in the form of a digital text file. The format of the metadata is compliant with the Federal Geographic Data Committee's metadata standards. Various items in the standard are critical for future spatial analysis and modelling. Of note are the *purpose*, *attribute accuracy* and *completeness report* categories because they provide end-users with the best indication of the fitness-of-use of the data. One objective of implementing the Federal Geographic Data Committee's metadata guidelines has been to facilitate better public access and hence more in-formed risk decision-making by local communities.

The research described in this thesis has integrated public and commercial datasets within a GIS. Through all stages of the thesis, metadata were never supplied with spatial data. This includes contour and spot elevation data from local surveying companies, permanent purvey markers (PSM) from the Queensland Department of Natural Resources, and contour and spot elevations from Queensland State mapping agencies. Regardless of the data custodian, obtaining metadata proved almost a futile exercise. In the case of PSM data, only after a personal visit to the Mackay office of the Department of Natural Resources, could accuracy statements be obtained.

This lack of metadata in the Cairns and Mackay study sites can be attributed to the reasons listed below.

- Custodians of spatial data may not appreciate the commercial value of their data and hence have no commercial data distribution structures in place. The perception is that requests for spatial data have only nuisance value and minimal effort is devoted to 'value adding' to the data.

- An unreasonable level of confidence is placed in the accuracy and precision of digital spatial data and high levels of accuracy are generally assumed.

- Custodians may not appreciate its significance because they do not use the data.

Given that data were provided free of charge, thanks to data sharing agreements, obtaining detailed metadata proved an illusive goal. This is a critical impediment to the successful integration of spatial data for natural hazard risk management, that also contains possible legal liability consequences. From a risk management perspective, it is recommended that where data are purchased or obtained through data sharing agreements, risk managers ensure compliance with ANZLIC metadata guidelines. Conversely, where risk managers are providing spatial data, compliance with metadata guidelines is similarly critical, to ensure that all data assumptions are made clear to end-users. To facilitate the creation of compliant metadata, ANZLIC has created a metadata input tool based on Microsoft Access. This is available at http://www.walis.wa.gov.au/meta/runtime.

3.7.6 Spatial Risk Data–Access and Sharing

Australian paper maps such as the AUSLIG 1:100 000 scale topographic maps have been a relatively inexpensive source of spatial data for many years. The digitisation of these has driven agencies towards commercial spatial data dissemination policies. Commercialisation is also driven by companies selling data (i.e. MapInfo Streetworks, ESRI ArcData). Changing data dissemination philosophies can hinder the access to spatial data for risk management at the local level because costs can be prohibitive. One solution is the establishment of data sharing agreements by risk management agencies with stakeholders. This has been a key feature of the Tropical Cyclone Coastal Impacts Project (TCCIP 1997) and has facilitated data exchange which would otherwise not have been possible. Natural hazard risk management stakeholders are in a unique position to initiate sharing agreements because they are often non-profit organisations, which seek to improve the public safety of the community. On these grounds alone, risk management agencies can obtain a level of co-operation and sharing not possible among private and commercial interest groups.

At both the national and state scale, there have been initiatives to improve access to spatial data by establishing spatial data directories. These are important starting points for natural hazard risk management, because they can help practitioners minimise data duplication and facilitate data exchange. Nationally, the Australian Spatial Data Directory (ASDD, more details available at http://www.environment.gov.au/database/metadata/asdd/) provides a WWW-based interface to search for spatial data. The ASDD contains a search-able index for a number of spatial data categories including *hazards*. As with the U.S. Clearinghouse concept, the directory contains only the metadata which conforms to the ANZLIC metadata standards. Because metadata contains custodian information, end-users can source the data directly from the custodian. Internet based spatial data Clearinghouses exist at the state level in Australia including:

- Victoria - Geospatial Information Victoria (GI Victoria) (http://www.giconnections.vic.gov.au/). Contains a search-able interface for all currently available spatial data in Victoria including topographic, satellite, aerial and other thematic data types.
- Western Australia - West Australian Land Information System (WALIS) (http://www.walis.wa.gov.au/search).

The natural hazard risk management community is also a custodian to important spatial data, of value to other interest groups. That is not to suggest that commercial gain should be an objective of data capture, but rather, where additional spatial data are sought, data sharing and exchange arrangements can minimise the cost to both parties. For example, U.S. agencies are encouraged to participate in spatial data Clearinghouses and 'concurrent with the creation of public access procedures, an agency must adopt internal procedures to ensure that the agency accesses the Clearinghouse before it expends funds for new data acquisition, in an effort to reduce data redundancy and duplication of efforts' (FEMA 1996) . In this thesis, elevation contours and spot elevations were obtained from a consortium of private companies associated with the sugar cane industry in Mackay. In exchange, two DEMs developed for flood inundation modelling were provided back to the consortium.

Concepts such as vulnerability, equity and social disadvantage have entered the natural hazard management lexicon. Human vulnerability issues also arise when access to spatial data is concerned. Schiller and Schiller (1988) summarise this, noting that 'transforming information into a saleable good, available only to those with the ability to pay for it, changes the goal of information access from an egalitarian to a privileged condition. The consequence of this is that the essential underpinning of a democratic order is seriously damaged. This is the ultimate outcome of commercialising information throughout the social sphere'. The equitable access to spatial data should also be a component of natural hazard vulnerability assessment. Spatial data equity issues can occur at various spatial scales. They can occur between local governments with different access to GIS and within local governments, or among members of the community.

3.7.7 Other Implementation Issues

Developing a user-needs assessment is a challenging aspect of integrating a GIS for natural hazard risk management. This is particularly true when organisations attempt to implement a GIS with little or no current investment in GIS. Because GIS is an enabling technology, its full capabilities may not be apparent to potential end-users. This introduces a common paradox of user-needs assessments: what do end-users require of a GIS when they are not familiar with the capabilities of a GIS ? A user-needs assessment can also provide an indication of costs-benefits of implementing a GIS specifically for risk management. GIS implementation costs have been discussed in detail by Dickinson and Calkins (1988) . Possible costs which risk managers should be aware of include:

- Feasibility study (needs assessment, bench marking)
- Hardware maintenance contracts
- Software maintenance contracts
- Database entry/transfer
- Database maintenance (edits, updates, backups)
- Training
- In-house programming for software enhancements
- Supplies

In Australia, such issues may be less of a concern when natural hazard risk management initiatives are developed in concert with local governments. Local governments will usually have the above structures in place for their corporate GISs and the use of a GIS for risk may be a relatively simple procedure of expanding the database to include key risk elements. For example, Table 4.1 shows the GIS platforms used in selected LGAs in coastal Queensland. An aspect of a GIS implementation that has received limited attention is the legal liability associated with the use of spatial data. Legal liability issues are linked to the lack of formalised quality standards within the GIS community. This is an issue of both the formal certification of GIS practitioners and the results and data which is derived from a GIS. There are two areas of liability that should be of concern to risk managers. First, there is liability for damages arising from the use of data that contains errors. Secondly, is the liability for damages arising from the application of data to a purpose for which it was not originally intended.

The second issue is related to issues of metadata discussed earlier. Epstein et al. (1998) provide one of the few research papers that addresses legal liability issues and GISs. Their study suggests that liability insurance for spatial data will become more common, as the consequences of spatial decision-making become more important. Before liability insurance can be obtained, spatial data providers will be required to 'posses formal quality assurance accreditation under a recognized standard' (Epstein et al. 1998). Issues of liability insurance and accreditation for decision-making based on GIS data are not unlike the legal liability issues emergency managers deal with. For a more complete treatment of this subject, risk managers are directed to the paper by Epstein et al. (1998).

3.8 Conclusion

The non-technical implementation issues presented are entwined with political/bureaucratic, economic and social factors. Some state governments already have extensive spatial data infrastructures and directories in place. Risk managers should play a key role in the establishment of these infrastructures in two ways; first, by adopting the designated standards for their own work and consequently contributing actively to spatial data directories; and secondly, by ensuring that natural hazard risk management is an issue which is considered in future spatial data capture efforts at the national, state and local government level. It is important that natural hazard risk management concerns are continually represented and that practitioners recognise that many of the impediments to successful GIS implementation remain non-technical.

The adoption of the risk management model for natural hazard disaster reduction poses challenges for GIS implementation and offers a rich area of future research. Existing examples of GISs applied to natural hazard disaster management have focused on one aspect of the conventional prevention, preparedness, response and recovery model (PPRR) of risk treatment. The adoption of the Standard is still in its infancy in Australia and relatively little attention has been given to how GIS can be integrated with the process (for one example, see Granger 1998). The following chapters examine the use of a GIS for storm surge risk mapping and risk management in Cairns and Mackay. The chapters are also case studies for various stages of AS/NZS 4360 applied to storm surge risk and described in detail in Section 3.5. Namely, each chapter addresses the following stages of AS/NZS 4360.

- Chapter 4: Risk identification
- Chapter 5: Risk identification / database development
- Chapter 6: Risk analysis and uncertainty analysis
- Chapter 7: Risk assessment, risk communication, developing criteria
- Chapter 8: Establishing the context and risk treatment