PERGAMON

Computers, Environment and Urban Systems
27 (2003) 123–141

Computers, Environment and Urban Systems

www.elsevier.com/locate/compenvurbsys

Impediments to using GIS for real-time disaster decision support

Andre Zerger[a,*], David Ingle Smith[b]

[a]Centre for GIS and Modelling, Department of Geomatics, The University of Melbourne, Victoria 3010, Australia
[b]Centre for Resource and Environmental Studies, Australian National University, Canberra 0200, Australia

Abstract

This paper examines and evaluates the application of GIS for cyclone disaster risk management, focusing on observations from a real-time emergency management disaster scenario held in Mackay in far north Queensland, Australia. Results from scenario observations and post-scenario interviews with risk managers highlight the limitations of GIS for real-time disaster planning. Limitations include the scale of spatial data and its suitability for regional-scale decision making and the risk manager's requirement for temporal detail rather than spatial detail. The paper also examines non-technical GIS impediments including custodianship and system implementation for disaster risk management. Findings have shown that the use of GIS for urban disaster risk management can readily fail due to implementation, user access and knowledge impediments, in addition to the availability of spatial data and models.

Keywords: Geographic information systems; Real-time disaster planning; Storm surge hazard; Scenario decision making

1. Introduction

There are reasons to believe that the utility of geographic information systems (GIS) for natural hazard risk and disaster management will expand as spatial databases become more widely available, the cost of software decreases and as risk managers acquire GIS expertise. It is also likely that GIS use will extend beyond mapping, towards a richer use of its spatial analytical capabilities. Invariably, risk managers will also demand access to decision support tools that allow them to manage and understand the complicated nature of disaster. It is likely that GIS-based risk and disaster management will become a feature of state and local

* Corresponding author. Fax: +61-3-934-2916.
E-mail addresses: a.zerger@unimelb.edu.au (A. Zerger), dingle@cres.anu.edu.au (D.I. Smith).

0198-9715/03/$ - see front matter
PII: S0198-9715(01)00021-7

government's natural hazard risk management procedures. This is already occurring in Australia as corporate GIS databases developed initially to manage land records, property values, planning and zoning regulations and other administrative tasks are being extended to accommodate natural hazard risk management needs. This paper examines the application and integration of GIS for storm surge risk management and disaster decision making. The study focuses on observations from a real-time emergency management disaster scenario held in Mackay in far north Queensland, Australia.

In addition to a range of other disaster risk management objectives such as testing vehicle response times, communication infrastructures and evaluating disaster plans, the scenario aimed to assess the utility of GIS for real-time risk decision making. Results from scenario observations and post-scenario interviews with risk managers highlight the limitations of this technology for real-time applications, and disaster management in particular. The research, however, shows that real-time disaster applications of GIS have very specific requirements which are significantly different from long-term decision making for disaster planning. These requirements are examined in detail as the lessons learnt may be valuable for other disaster management planning utilising GIS. Finally, the paper examines non-technical GIS implementation issues that have arisen from the Mackay scenario as these may be a greater barrier to GIS-based disaster management than technical issues of software, hardware and spatially explicit modelling.

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 they have varying magnitude, temporal and spatial dimensions and varying social and economic consequences. In this paper, disasters are synonymous with rapid onset natural hazards (i.e. storm surge). Blaikie, Cannon, Davis, and Wisner (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. A disaster cannot occur if elements at risk do not coincide with natural hazard impact zones such as floodplains, earthquake zones or bushfire prone vegetation types. The terms 'risk' and 'disaster' refer to damage that can only exist in the presence of a vulnerable community (Cannon, 1994; Hewitt, 1983). This philosophy of disaster challenges the historical emphasis on technological solutions to disaster reduction.

The theoretical basis for vulnerability-focused disaster management has existed in the academic literature for some 50 years. The pioneering work of White (1945) and later work of Hewitt and Burton (1971), Burton, Kates, and White (1978) and Hewitt (1983) has established the foundation for a vulnerability approach to hazard and disaster management. Hewitt's (1983, p. 13) thesis argues that the 'technocratic' 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 like statistics or remote sensing. The research is essentially an empirical study of questions specified by an agency's responsibility...'. In the context of this paper, a number of non-technical GIS implementation issues are examined in further detail using Mackay as a case study. Case study conclusions indicate that these implementation issues may limit the utility of GIS for real-time disaster applications, even more so than the technical issues of modelling, software and spatial data so commonly addressed in earlier studies.

3. GIS-based disaster decision support—existing case studies

Most initiatives that integrate GIS for hazard and disaster decision support have arisen in the last decade. GISs did play an earlier role but were relatively primitive, rarely commercially available and often experimental or research focused, rather than operational. This literature review examines the application of GIS for disaster decision support paying particular attention to real-time scenario analysis. Examples commonly focus on technical specifications of GIS software systems, spatial data themes, spatial data capture techniques, modelling of the hazard and its spatial extent, cartographic presentation of results and other technical considerations (for examples, see Dymon & Winter, 1993; Lipschultz, 1988; Nagle, Ochs, Bruzewicz, & McKim, 1995). Similarly, much of the research that integrates GIS and hazard studies have been restricted to producing cartographic products rather than spatial modelling within a GIS environment. Newkirk (1993b) provides historical reasons for this trend noting that many commercial GISs have evolved from mapping tools and their functionality has only recently been extended to modelling and simulation.

Studies that address the institutional, political, managerial, social and human dimensions are rare. This technical focus has parallels with the historical focus of natural hazards research that has received ongoing criticism (Cannon, 1994; Hewitt, 1983; Wisner & Henry, 1993). These dimensions may be a greater barrier to successful implementation of a GIS than the technical impediments commonly presented. These implementation barriers are discussed in detail in later sections of the paper. The three reviews by Coppock (1995), Emani (1996) and Eastman, Emani, Hulina, Johnson, Jiang, and Ramachandran (1997) which examine the integration of GIS and natural hazards have made an important contribution to the discipline. Coppock's study provides a broad conceptual examination of issues with an emphasis on evolving natural hazard philosophies and changing paradigms. In contrast, Emani's study provides GIS examples grouped by natural hazard type with an emphasis on presenting a diversity of applications. Finally, Eastman et al. (1997) review case studies within a risk management framework with an emphasis on hazard assessment. This review examines the integration of GIS for natural hazard risk modelling and disaster studies with an emphasis on real-time disaster decision support. The lessons learnt from these case studies and the research presented in this paper is critical as GISs evolve into real-time risk management decision support systems.

GIS-based evacuation modelling has received particular attention in natural hazards research. Examples are of interest to hazard risk management because they commonly integrate physical hazards and population data. Historically, evacuation planning arose from the need to move people living in close proximity to nuclear power plants and chemical storage sites (Jeanes, 1993). Disasters at the nuclear reactor at Three Mile Island in 1979, and Chernobyl in 1986 have been major disaster events that have driven some of these initiatives. In their study of modelling community evacuation vulnerability using GIS, Cova and Church (1997) adapted the concept of an emergency planning zone (EPZ). They note that the EPZ concept has been a useful construct for evacuation planning because '. . .it serves as a formal agreement among emergency planners regarding the definition of a likely evacuation. This allows analysts to move directly to issues related to estimating and reducing the time it may take to clear a zone. . .delimiting a credible EPZ can be a significant political and technical endeavor for certain hazard types' (Cova & Church, 1997, p. 764). A GIS can therefore provide a planning base for decision making among stakeholders, where decision making ambiguity may otherwise exist.

De Silva, Pidd, and Eglese (1993) provide an example of a spatial decision support system (SDSS) for emergency planning that interfaces simulation models and commercial GIS software to model evacuation routes for radiological disasters. The SDSS uses the spatial data structure and network modelling algorithms of the GIS, combined with programmed simulation models to predict traffic flow through the network under various scenarios (vehicle breakdowns and road closures). The SDSS is designed as a contingency planning tool to evaluate a range of management strategies prior to an event. Real-time simulations are not possible because the system models the behaviour of individual vehicles and is therefore relatively time intensive.

Similarly, Newsom and Mitrani (1993) integrated the DYNamic EVacuation (DYNEV) model of traffic evacuation with a GIS to model the evacuation of persons living within 10 miles of a commercial nuclear power plant. The model accounts for vehicle flow rates and directions, vehicle occupancy, vehicle volume on roads and census data to predict the number of vehicles evacuating, road network carrying capacities and destination nodes including evacuation shelters. As is increasingly common, computerised numerical modelling integrated with a GIS provided a modelling environment that neither system could provide independently. Von Braun (1993) notes that GIS is particularly useful for integrating modelling results in time and space, for assessing exposure and risk and for assisting remedial decision-making. Cavallin and Floris (1995) describe an example of a raster-based GIS applied to ground-water pollution risk assessment. Hickey and Jankowski (1997) provide an ambitious, integrative case study of GIS, remotely sensed satellite imagery, erosion modelling and multi-criteria decision making methods to support land reclamation procedures for abandoned mines. In contrast to other case studies, a graphical user interface was developed for the project to create a decision support tool. However, the researchers conclude that even with the high levels of sophistication, the main limitation of the project was accurate spatial data. Data quality rapidly became the factor that determined the success of the initiative.

In contrast to relatively simplistic applications of GIS which utilise their cartographic strengths (Johnson, 1994; Mather, 1993; Smith & Greenaway, 1994), Lanza and Siccardi (1995) outline a methodology for assessing flood hazards by integrating GIS and distributed hydrological modelling. A GIS was used to derive inputs for distributed rainfall-runoff modelling, and combined with remotely sensed imagery to identify the possible occurrence of extreme meteorological events. This is termed a 'hydrologically oriented' GIS because the system is used to derive geomorphologic data of catchment descriptors within the GIS. As with other studies, the physical hazard modelling is carried out external to the GIS because the numerical modelling capabilities of GIS are limited (see Brooks & Tidwell, 1993, for an example of integration of a hydraulic model with a GIS). Hazelton (1991) provides a detailed discussion of hydrologic and pollution modelling using GIS.

From a commercial perspective, one of the most important application areas is emergency services dispatch. Public emergency management agencies including ambulance, police and fire services are adopting GISs, and global positioning systems-based dispatch systems. Schwarz (1989) notes that GIS for dispatch are now used in three capacities: automated geo-referencing and routing, automated mapping and planning and analysis. Victorian Emergency Services (Australia) has recently implemented an Intergraph (Intergraph Corporation, 2000) GIS dispatch system for logging calls, and coordinating its daily response activities for fire, police and ambulance services. Although dispatch and communication is its main function, the entire system is integrated within a GIS framework (Spring & Douglas, 1995).

A practical example of a GIS applied to cyclone risk management is presented by Johnson and Smith (1994) for south Florida. The study combines US National Weather Service storm surge inundation zones from Sea Lake and Overland Surge from Hurricanes (SLOSH) modelling with 100 year flood maps (Mercado, 1994). These are overlaid with municipal boundaries, section boundaries and land use types. Aggregate statistics are generated to estimate the number of properties affected by a category five cyclone. The authors note that in the future, individual parcel-based analysis would provide more specific vulnerability information for evacuation planning. Vermeiren and Watson (1994) provide a more complex example of hazard risk modelling for storm surge by integrating numerical modelling and GIS. The 'arbiter of storms system' (TAOS) was developed to interface with commercial GISs by sharing the same spatial data structures. A GIS provides spatially referenced inputs to TAOS and for visualising model results including wind speeds, still water heights and maximum wave heights. Numerical modelling is more effectively achieved outside a GIS, because a GIS has limited capabilities for modelling and simulation (Newkirk, 1993a). However, most case studies that integrate GIS with modelling and simulation do not have a real-time capability and require events to be pre-modelled.

Studies have also adapted the cartographic capabilities of a GIS for cyclone hazard risk management (Dymon & Winter, 1993, Rosenfeld, 1994). Dymon and Winter's study of map use during Hurricane Andrew found that the most common real-time need was for maps showing the pre-event distribution of all houses in Dade County. Requests from emergency managers were for relatively simple cartographic output. Dymon's conclusion raises an most important aspect of GIS technology. A GIS is an enabling technology that allows people to ask questions that they did not know they previously could. A lack of familiarity with GIS concepts and capabilities may have limited more complex spatial requests. This is indeed a key outcome of the forthcoming case study in Mackay.

The case studies examined in the previous discussion range from relatively simple local-scale hazard mapping to interactive decision support systems. Some researchers have noted that the current generation of commercial GISs are unable to facilitate real-time natural hazard risk management decision-making without significant modifications or integration with external models. This restriction is driving the next generation of SDSSs which integrate GIS, dynamic models and graphical user interfaces, to provide disaster management decision support tools. Regardless of these limitations, one must put the current state of knowledge in a temporal context, as most of the progress has only occurred in the past 10 years. The following section examines a real-time disaster scenario developed to test the utility of GIS for real-time decision support in Mackay. Conclusions and lessons learnt from the exercise are valuable for the long-term decision utility of GIS for real-time disaster management.

4. The 'MkAttack' disaster scenario

4.1. The disaster study site

Mackay is a rural community located in far north coastal Queensland with a population of 70,000 people. It is surrounded by sugar cane and a third of Australia's export sugar crop is produced in this region producing over $AUD300 million annually. In fact, the worlds largest sugar-loading terminal is located at Port Mackay about 15 km north of Mackay City. Mackay City is located on the estuary of the Pioneer River, with its main business district on the southern side of the river (Fig. 1). Mackay is particularly interesting as a case study for storm surge disaster owing to the high tidal range of 7.0 m which makes it one of the most tidal coastal communities in Australia. A large tidal range means that the time that water levels are within a metre of maximum high water will be reduced, therefore reducing the chance that a surge will coincide with the high tide level. Similarly, if the tide is at its maximum, the consequences can be disastrous.

Although the incidence of category four and five cyclones is uncommon, Australia's largest cyclone-related disaster, Cyclone Tracy, had maximum reported wind gusts of at least 217 km/h, which is consistent with only category three cyclones (Oliver, 1979). Category three cyclones are reasonably common in the Australian tropics and the main disaster mitigating factors are the low population densities in

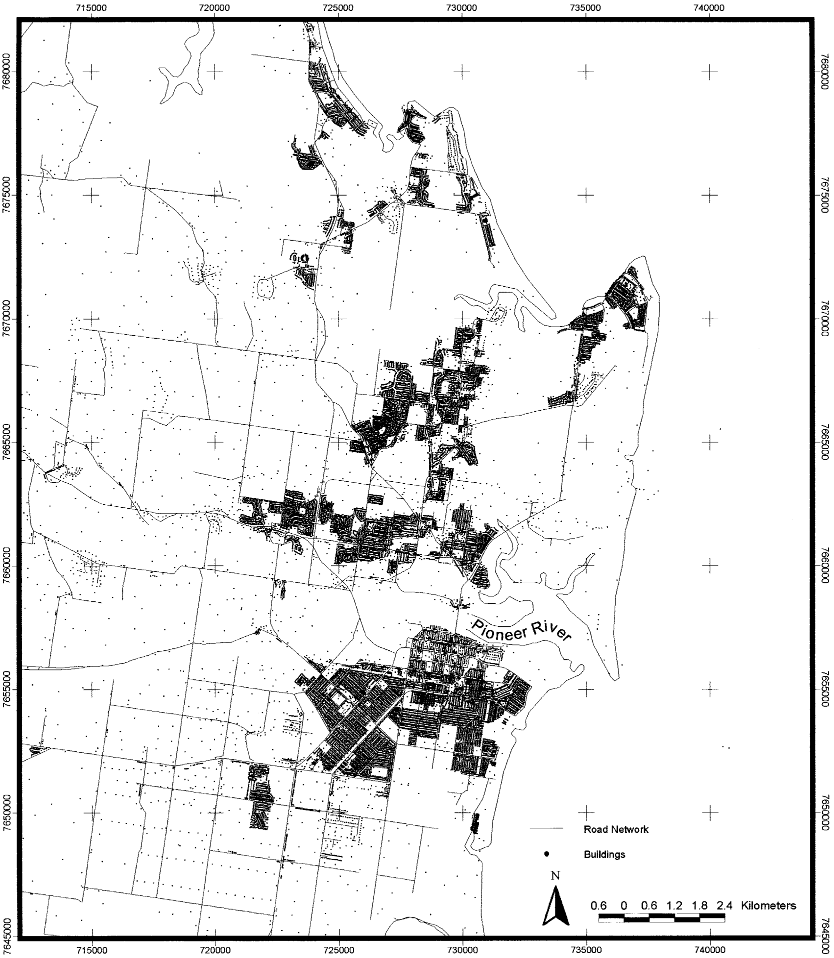

Fig. 1. Extent of building risk database and road networks in Mackay.

these regions (Fig. 2). In addition, many category three, four and five cyclones may have occurred prior to current levels of urban development and before recent cyclone detection technologies such as meteorological satellites became operational.

Although storm surge-related disasters are relatively rare in Mackay, a 1918 event in Mackay has been well documented and provides invaluable information for assessing current risks in the city. The event of 21 January 1918 resulted from a category four cyclone (wind gusts of 225–280 km/h) producing a storm surge of 3.7 m and partly submerging the city. The death toll approached 30 (13 drowned) with most of the 1400 homes being damaged. Costs were estimated at $2 million (1918 dollars). If this event were repeated today, a total of 1571 dwellings would be at extreme risk of damage and destruction (greater than 1 m of water above floor height), 1174 would be at high risk (less than 1 m of water above floor height) and

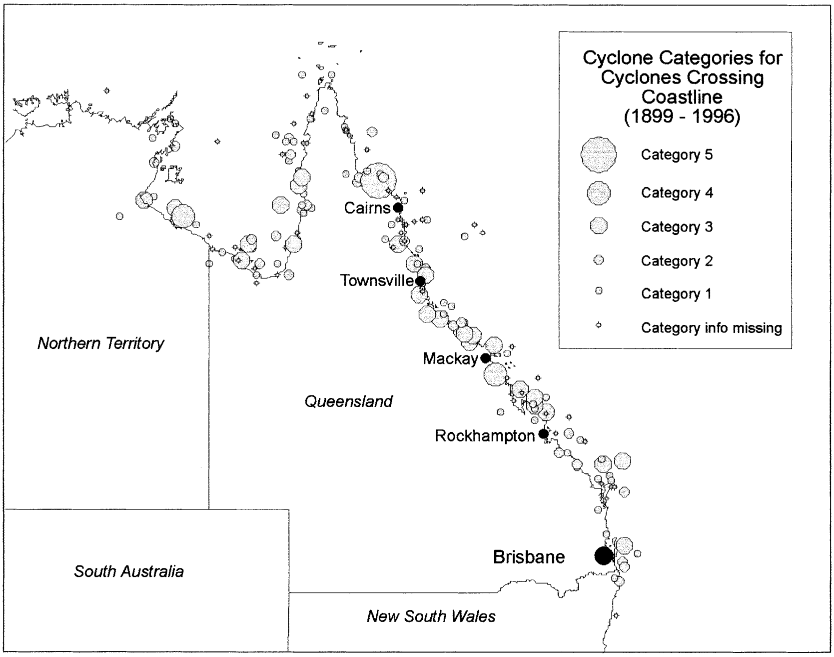

Fig. 2. Tropical cyclones that have made landfall in north-eastern Australia derived from the Australian Bureau of Meteorology Tropical Cyclone Database.

977 with minor risk (water on property but not over-floor; Smith & Greenaway, 1994). Harper (1998) estimates that with a 1 in 100 year recurrence interval, the storm surge in Mackay would be 4.1 m (above the Australian Height Datum).

4.2. A GIS to support disaster scenario decision support

An important indication of urban risk are the buildings and roads that will be inundated (and the magnitude of the inundation). This information is critical for pre-disaster and real-time disaster planning. Detailed building databases were developed from previous work by Smith and Greenaway (1994), from additional field work, and building databases integrated from council property management systems. The final spatial database is unique as it is one of the largest and most accurate developed for natural hazard disaster management in Australia. A total of 10,800 buildings in Mackay were integrated into the GIS (Fig. 1). Other spatial datasets developed for the decision support tool included road networks for evacuation planning (Fig. 1), digital elevation models for flood risk assessments (Fig. 3), the locations of important facilities including hospitals, fire and police stations and population distributions from the Australian Bureau of Statistics CDATA product.

A major component of the research was to pre-model storm surge risk in Mackay. Flatwater surge inundation was modelled by incrementally increasing the inundation

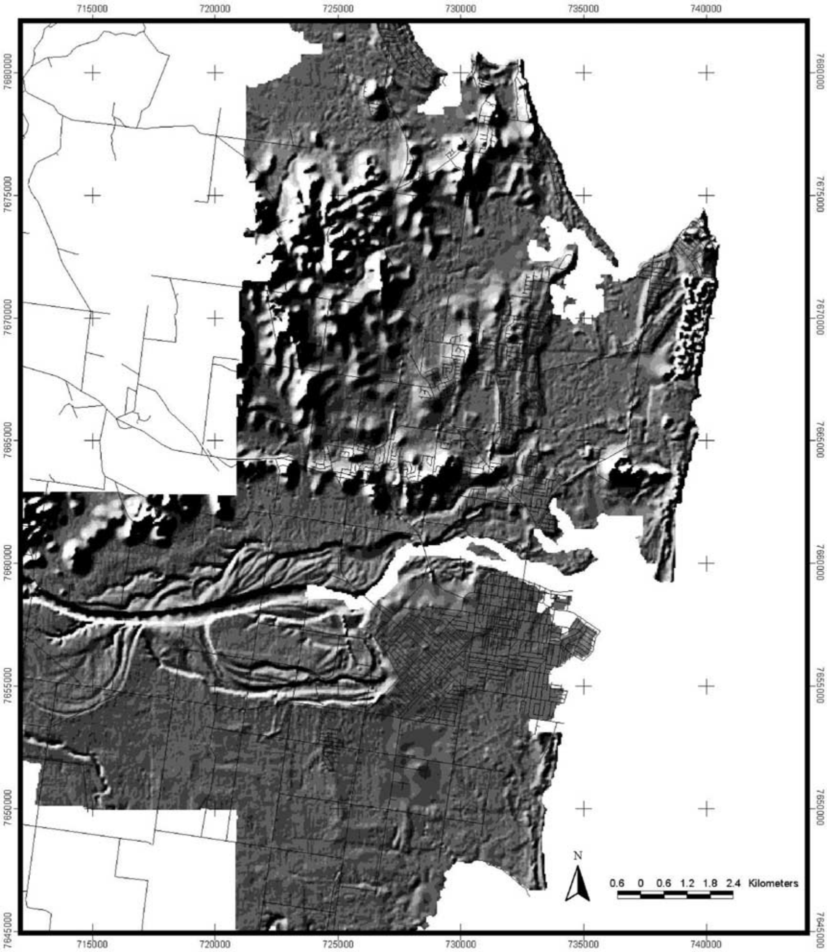

Fig. 3. Mackay 30-m digital elevation model shown using analytical hillshading.

level and assessing the resulting building and road flooding. This is a basic form of sensitivity analysis which is a generalised methodology for measuring the result of a model output, to variations in its input components (Emmi & Horton, 1995). The inundation model has been implemented using ARC/INFO (ESRI, 1997) GIS and the Arc Macro Language. A horizontal inundation surface represents the flooding level for the study area, where the flood height is calculated relative to the Australian Height Datum. Inundation is determined by the following factors: (1) the ground elevation at each building and road; (2) the building floor heights derived from field work; and (3) the storm surge inundation modelled using the flatwater model from a digital elevation model. Hence the final outcome of the modelling is an additional attribute for each building and for each flood level that indicates the extent of flooding for each storm surge scenario. In this way the risk estimates are pre-modelled and included as attributes in the GIS database.

4.3. Broader research context

The Mackay disaster scenario was a component of a broader research initiative that aimed to assess the GIS risk management needs in far north Queensland, Australia. The aim of the research was to develop GIS-based storm surge risk modelling methodologies that have practical utility for risk managers and local government. The methodology aims to account for constraints that may limit its practical implementation including software and hardware, spatial data availability, model accuracy requirements and ultimately its utility for improved decision making. The broader objectives of the research included:

1. development of a GIS methodology to model the risk associated with storm surge hazard and vulnerability;
2. development of a methodology to identify emergency management 'hot spots' and 'catchments';
3. assessment of the role of GISs in the risk and disaster management process;
4. to contrast two study sites, Cairns and Mackay, with different risk management needs;
5. determining whether generic GIS/spatial analysis techniques can be applied to other hazard prone communities in Australia while accounting for existing technical GIS constraints;
6. developing a methodology that can be assessed in the context of improved decision-making; and
7. to test the effectiveness of real-time GIS-based disaster decision-making.

4.4. The Mackay disaster scenario

The focus of this research is the 'MkAttack' cyclone emergency preparedness exercise held in Mackay. Among a range of disaster management objectives, the exercise was designed to examine the utility of GIS to support real-time disaster risk management, emergency planning and decision support. The exercise was developed by the Emergency Services Division, Queensland Department of Emergency Services (DES), to evaluate the state of preparedness of the disaster management system within the Mackay Disaster District (Morrison, 1996). The exercise was run as a one day (05:00–15:00 hours) paper exercise with no actual allocation of resources. Over 50 participants were asked to provide realistic responses. Exercise participants included individuals from: (1) Mackay Police Station (Communications Centre); (2) Mackay Police District Office; (3) Emergency Services Division, Regional Office; (4) State Emergency Service District Office, Mackay; (5) Mackay City Council; (6) Sarina Shire Council; and (7) a private company of consulting engineers to provide technical flooding advice. The exercise scenario was designed to prompt the following actions to occur (Morrision, 1996):

1. notification and activation of the Disaster District Coordinator and relevant Chairpersons and exercising Local Government counter disaster committees;
2. an operational briefing of relevant Control Group members by the District Disaster Committee;
3. the implementation and operation of an effective operational management system between the Local Government Disaster Coordination Centres (LGDCC), the Disaster District Coordination Centre (DDCC) and the State Disaster Coordination Centre (SDCC); and
4. decision-making processes in regards to impending community threats and the input of control traffic.

'MkAttack' was based on a fictitious cyclone impacting on Mackay and resulting in heavy rain along the coast for some days prior to cyclone impact giving rise to wind damage, storm surge and flooding of the Pioneer River. The hypothetical Bureau of Meteorology cyclone advice (1200 EST 27 November 1996) issued for the region described the event as a category four cyclone, located 55 km northeast of Mackay with extreme wind gusts up to 240 km/h. An objective of the exercise was to appraise the accessibility and management of GIS data to determine the risk, vulnerability, evacuation shelter criteria and the viability of access and egress routes. From the perspective of this research, the exercise was an opportunity to observe the practical application of GIS for natural hazard risk management and to:

1. assess the appropriateness of spatial data layers for cyclone hazard management;
2. examine the utility of GIS software for decision-making in crisis situations;
3. assess the spatial data needs of emergency managers in a crisis situation;
4. examine the institutional and management requirements for successful hazard risk management and GIS implementation at a local government level; and
5. identify the requirements of an emergency management GIS.

To evaluate the above factors, a post-disaster scenario user perception study was developed. Because GIS research is often quantitative, most examples of user perception studies associated with a GIS implementation and its spatial outputs are also quantitative (see Crossland, Scudder, Herschel, & Wynne, 1993; Schweizer & Goodchild, 1992; Todd, 1995). Quantitative techniques, however do not necessarily elicit the information required from the subjects. For example, Robson (1993) notes that when carrying out an enquiry regarding humans, 'why not take advantage of people's ability to tell you things about themselves and their perceptions.' Quantitative techniques were also not appropriate for this research owing to the small sample size of risk managers involved in the disaster scenario and whom had some access to GIS (nine individuals). The following discussion is a summary of the results of the post-scenario semi-structured interviews presented to disaster managers. Respondents included staff from the Bureau of Meteorology, Queensland Police, Mackay City Council and Queensland Department of Emergency Services.

5. Disaster scenario results

'MkAttack' was the first test of the GIS operationally as a response tool during the onset and impact stages of a cyclone and Queensland DES anticipated its widespread use during the exercise. Administering the semi-structured interviews immediately after the 'MkAttack' exercise proved invaluable as respondents were enthusiastic and motivated when answering questions and providing feedback. More indifference may have been expected at other times when cyclone risk management has a lower profile in the community. Somewhat unfortunately, the GIS was rarely relied upon to aid decision-making during the scenario and remained relatively dormant as a decision support tool.

Before examining the reasons for its under utilisation, it is worth noting some of the responses garnered from emergency managers to establish the context. A common theme was the general requirement for paper maps that was illustrated by the following responses: 'If GIS access is too slow then paper maps would be useful for quick reference' and 'Provided the scale is suitable, papers are not affected by power failures. Computer-based GIS may provide much greater detail but which cannot necessarily be utilised in a disaster situation. Computer GIS is perfect for planning and preparation'. And finally, a pragmatic observation that 'groups of people would prefer to discuss emergency task around a large scale map on a table, than rely on a computer operator to display the same information on a computer screen'.

A number of respondents commented on the top-down implementation issue that neglects the unique requirements of emergency managers noting that: 'A team approach to outcomes needs to be developed rather than say Canberra [Australia's centre of federal government and hence the home to a number of agencies responsible for emergency management] introducing [sic]...when a simpler approach may be more applicable. Computing time needs to be kept to a minimum for hazard management use' and 'Application design must be specifically tailored to the emergency manager/user. A few critical options on menu (with advanced enquiries available on to the experienced GIS users)'. Interestingly, a number of respondents also responded with the view that operational or real-time decision making needs are small, in comparison to their broader risk management responsibilities: 'Not so interested in the technical operating issues as in how to maximise the utilisation of information from a broad perspective i.e. the interconnections of mitigation planning, response planning and recovery planning. Operational decision making is a relatively small, although an important component of the overall benefits to be gained'. Other reasons for this under-utlisation and relative dormancy of the system during 'MkAttack' include the following:

1. The GIS was unable to provide the answers asked of it in real-time due to technical constraints that included limited computer processing power and the size of building database. The building database size in particular prevented GIS operators from providing answers to fundamentally spatial questions in a time frame suitable for decision making. For example, simple structured query

language (SQL) statements issued to the GIS took in excess of 5 min to generate a map. For real-time evacuation planning this was too long.

2. Emergency managers were occupied with more pressing evacuation and decision making concerns than those which the GIS had been designed to address. For instance, much of the disaster scenario decision making was concerned with resource allocation such as the maintenance of utilities including power, gas and water and allocation of emergency service vehicles such as police, ambulance and fire services. This resource allocation was achieved via radio communications and clearly if the GIS were to be useful in the future, real-time vehicle tracking would be critical to its success.
3. The GIS was designed without considering the operational requirements of emergency management personnel in a response situation. Specifically, the operational requirements in such scenarios appear to require temporal resolution rather than spatial resolution. For instance, emergency managers were more concerned with the general movement of people and vehicles rather than spatial precision and high spatial resolution. The questions and decisions pertaining to 'when' dominated the 'where' concerns for emergency management and evacuation planning.
4. The vulnerability data (residential and commercial buildings) were too detailed for emergency management because most emergency management issues focused on regional scale decision-making (i.e. across the entire Mackay Shire rather than only Mackay City). In terms of prioritising evacuation decision making, an outcome of the scenario was an appreciation of the spatial generalisation involved in issuing evacuation orders. Providing individual building risk information in a real-time scenario provided an unwarranted level of spatial detail.
5. The inexperience of emergency managers with GIS precluded them using it to aid decision-making to its full potential. Emergency managers were not familiar with the spatial analysis capabilities of the GIS and the range of spatial operations available within it. There remains a perception that a GIS provides cartographic capability rather than a spatial modelling and analysis capability. That is not to say that emergency managers have limited cognitive spatial reasoning abilities, but rather a lack of familiarity with the capabilities of spatial analysis in a GIS framework.
6. The size of computer screens does not provide necessary detail for regional scale emergency management decision making. This makes it difficult to relate computer-based output to broad scale decision-making. For example, a regional view of Mackay removes any local scale spatial detail.
7. Difficulties in sharing information via a single computer terminal to multiple users.

From questionnaires and the post-exercise interview, the best method for communicating hazard risk information to decision-makers is to pre-model risk using the GIS and to present results as paper maps. Most respondents believed that paper maps would be more useful than computer-based GIS displays. Although GIS may provide a decision support role, its utility in real-time hazard management appears to be limited with current levels of sophistication and computer processing restrictions. Interviews highlighted the general inertia among users to utilise GIS for real-time decision making where paper maps have been used for decades. This barrier is coupled with a general lack of familiarity with a GIS and its analysis and modelling capabilities. Hence, the functionality and decision support role of a SDSS has not been realised in this work.

Similar conclusions were observed in other studies including the work of Dymon (1993) who evaluated map use during and after Hurricane Andrew in Florida. Dymon's study found that the spatial data needs of emergency managers were simpler than expected. An essential element of the GIS was the ability to provide paper maps of spatial features including road networks, hurricane shelters, Red Cross facilities and community health centres. Rarely was advanced GIS spatial analysis required because the main requirement was for cartography.

Although participants in the 'MkAttack' exercise had little GIS experience or formal training and limited access to GIS in their workplace, answers provided to the question 'List questions which you would like a GIS designed for hazard management to be able to answer?' illustrate the potential utility of GIS. In all cases, the risk manager's questions would require some form of spatial query and in a number of cases, relatively sophisticated spatial analysis including map overlay and proximity calculations. Bearing in mind the earlier responses to the interviews, the spatial data developed for the Mackay GIS is sufficient to answer most questions posed. From this, the general lack of utilisation of the GIS during the scenario could be attributed to reasons other than data availability, data accuracy and data suitability. This is an important conclusion as most GIS-based disaster research places a major emphasis on spatial data issues such as accuracy, scale and detail, analysis and modelling at the expense of implementation issues which may pose a greater impediment. For instance, one important outcome of the research is a recognition that risk managers require more formal and ongoing GIS training.

6. The technical paradigm: its relevance for GIS-based disaster studies

A GIS is fundamentally a technical tool for disaster reduction. GIS literature suggests that, historically, the fundamental challenges are software, hardware, data capture, fitness-for-use and physical hazard modelling in a spatial framework. This technical focus of GIS is analogous to the historical treatment of disaster events as only functions of the physical hazard. Hewitt (1983) terms this the 'dominant' view, characterised by the notion that disaster is solely attributed to nature and that society can alter nature's course (see Rayner, 1992, for a treatment 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, frequency and hazard detection. Salter (1995) notes that the problem with treating disasters as only a physical event, with technological solutions, is that society limits the number of intervention options available. As with disaster studies, the use of GIS for disaster management also introduces a range of social and political factors that for the purposes of this paper are referred to as 'implementation issues'. Implementation issues are also common with other facets of hazard risk management. For example, the successful establishment of warning systems, landuse mitigation strategies and the establishment of evacuation routes can be hindered by the same social, political and institutional constraints. This historical technical focus within the GIS research community can be attributed to two major factors:

1. technical constraints needed to be overcome before GIS could be integrated into practical decision-making and now these issues are beginning to emerge; and
2. the traditional focus 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.

A barrier that may have prevented more effective use during the Mackay disaster scenario was the mechanism of technology transfer. The risk management GIS had been effectively developed without broader consultation with risk managers in Mackay and was delivered as a final product with limited user training. Although this pathway of GIS integration for the 'MkAttack' scenario was limiting, the exercise has nevertheless educated emergency management staff to the potential and limitations of GIS in an operational context. A user-needs assessment conducted at this stage would be particularly valuable. In contrast, the implementation process in Mackay anticipated user needs, integrated the spatial data, developed the GIS and provided it to risk managers for real-time decision support.

Ventura (1989, p. 827) has labeled this a top-down strategy where '...a single entity such as a central office of a federal agency with many field offices designs a system and selects hardware and software for all the field offices...A top down strategy seems to satisfy a national office's interest...they have only one system for which they must provide advice and technical support, they fulfill their mandate and they provide a solution that will work for at least some of the intended clients.' Shackley and Wynne (1995, p. 117) examine similar issues in regard to climate change modelling. They discuss the interactions between modellers, their model outcomes, and the actual relevance for impact studies, noting that: 'On the whole, GCMs [global circulation models] have not been run for the benefit of the impacts community, but for the purposes of model development, testing and validation...As a result, the availability of suitable output for impacters has been difficult and somewhat random'.

From the perspective of implementation impediments, data custodianship is another critical issue to emerge from the research. At the time of the disaster scenario, Mackay City Council possessed two GISs including the MapInfo disaster management GIS and the corporate Genamap GIS. The corporate GIS has important advantages over the disaster GIS because it is staffed by trained GIS technical staff, spatial databases are current, it contains other building and feature attribute information useful for risk management and its spatial extent is larger. Implementation issues such as custodianship and technology transfer are significant impediments for the successful use of GIS for disaster management. Until disaster management is integrated into a corporate GIS, the utility of a disaster or risk management GIS is limited. This is particularly a problem as time erodes spatial data currency and staff remain untrained and inexperienced with GIS technology. Such integration may also encourage hazard risk management to be integrated into urban planning and zoning activities thereby moving towards a risk management paradigm for mitigating disaster. Experiences in Mackay illustrate how barriers to GIS implementation may include political and administrative structures rather the technical constraints including spatial data, hardware, software and spatial risk modelling.

7. Conclusion

Urbanisation in coastal regions such as Mackay is rapidly increasing, and in contrast to the hazard agent, action can be taken to mitigate the disaster by reducing community vulnerability. In addition to measures such as land-use planning, residential insurance, preparedness and education programs, GIS are important as they can allow decision makers to model scenarios and interact with the spatial dimension of a disaster. However, the suitability of GIS for planning versus real-time applications is quite different. Results from the 'MkAttack'' scenario have shown that the utility of GIS for real-time decision making is questionable owing to a number of practical and implementation impediments including the requirement for paper maps, lack of training, computational overheads when analysing large urban databases, and the need for temporal resolution rather than spatial detail. Results from the broader research initiative have also highlighted the common incompatibility between the scale and resolution of human disaster decision making, and that of spatial data and models. Addressing this incompatibility is critical if successful use is to be achieved in the future. Although the research has focused on natural hazard disaster management, lessons learnt from this experience could be extended to other applications that attempt to integrate GIS for real-time decision support.

Acknowledgements

This research was funded by the Australian Organising Committee for the International Decade for Natural Disaster Reduction. Research was integrated within the Tropical Cyclone Coastal Impacts Project (TCCIP). Thanks are extended to Mr. K. Granger (Australian Geological Survey Organisation), Queensland Department of Emergency Services, Mackay City Council and Emergency Management Australia.

References

Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (1994). *At risk: natural hazards, people's vulnerability, and disasters*. London: Routledge.

Brooks, C., & Tidwell, J. (1993). Regional uses of geographic information systems technology. In *Proceedings of the seventeenth annual conference of the association of floodplain managers* (pp. 91–96). Atlanta, Georgia.

Burton, I., Kates, R. W., & White, G. F. (1978). *The environment as a hazard*. New York: Oxford University Press.

Cannon, T. (1994). Vulnerability analysis and the explanation of 'natural' disasters. In A. Varley (Ed.), *Disasters, development and environment* (pp. 14–30). Chichester: John Wiley.

Cavallin, A., & Floris, B. (1995). GIS potential for regional and local scale groundwater hazard assessment. In A. Carrara, & F. Guzzetti (Eds.), *Geographical information systems in assessing natural hazards, Vol. 6* (pp. 259–272). Netherlands: Kluwer Academic.

Coppock, J. T. (1995). GIS and natural hazards: an overview from a GIS perspective. In A. Carrara, & F. Guzzetti (Eds.), *Geographical information systems in assessing natural hazards, Vol. 6* (pp. 21–34). Netherlands: Kluwer Academic.

Cova, T. J., & Church, R. L. (1997). Modelling community vulnerability using GIS. *International Journal of Geographical Information Systems*, *11*, 763–784.

Crossland, M., Scudder, J. N., Herschel, R. T., & Wynne, B. E. (1993). Measuring the relationships of task and cognitive style factors and their effects on individual decision-making effectiveness using a geographic information system. *Proceedings of the 26th annual Hawaii international conference on systems sciences* (pp. 574–584). Hawaii.

De Paratesi, S. R. (1989). Hazards and disasters: concepts and challenges. In E. C. Barrett, & K. A. Brown (Eds.), *Remote sensing for hazard monitoring and disaster assessment: marine and coastal applications in the Mediterranean region* (pp. 1–17). Philadelphia: Gordon and Breach.

de Silva, F., Pidd, M., & Eglese, R. (1993). Spatial decision support systems for emergency planning: an operational research/geographic information systems approach to evacuation planning. In J. Sullivan (Ed.), *International emergency management and engineering conference* (pp. 130–133) Society for Computer Simulation.

Dymon, U. J. (1993). *Map use during and after Hurricane Andrew*. The University of Colorado, USA: Natural Hazards Research Center.

Dymon, U. J., & Winter, N. L. (1993). Evacuation mapping: the utility of guidelines. *Disasters*, *17*, 12–24.

Eastman, J. R., Emani, S., Hulina, S., Johnson, A., Jiang, H., & Ramachandran, M. (1997). Applications of geographic information systems (GIS) technology in environmental risk assessment and management. In UNEP (Ed.),, *The Idrisi project, Clark labs for cartographic technology* (pp. 1–10). Worcester, MA.

Emani, S. (Ed.). (1996). *GIS applications in hazard assessment and management*. Geneva: UNITAR.

Emmi, P. C., & Horton, C. A. (1995). A Monte Carlo simulation of error propagation in a GIS-based assessment of seismic risk. *International Journal of Geographical Information Systems*, *9*, 447–461.

ESRI. (1997). *ARC/INFO*. Redlands, CA: Environmental Systems Research Institute.

Harper, B. (1998). *Storm tide threat in Queensland: history, prediction and relative risk*. Brisbane: Department of Environment and Heritage.

Hazelton, N. W. J. (1991). Using GIS with non-point-source and distributed models: the 'why' and 'how' of an information opportunity. In *AURISA 91, Australasian urban and regional information systems association* (pp. 289–313). Wellington, New Zealand.

Hewitt, K. (1983). The idea of calamity in a technocratic age. In K. Hewitt (Ed.), *Interpretations of calamity* (pp. 3–32). Boston: Allen and Unwin.

Hewitt, K., & Burton, I. (1971). *The hazardousness of a place: a regional ecology of damaging events*. Toronto: University of Toronto Press.

Hickey, R., & Jankowski, P. (1997). GIS and environmental decision making to aid smelter reclamation planning. *Environment and Planning A*, *29*, 5–19.

Horlick-Jones, T. (1993). Communicating risks to reduce vulnerability. In P. A. Merriman, & C. W. A. Browitt (Eds.), *Natural disasters: protecting vulnerable communities* (pp. 25–37). London: Thomas Telford.

Intergraph Corporation (2000). *Intergraph MGE GIS*. Avaliable at: http://www.intergraph.com/, Huntsville, AL.

Jeanes, P. (1993). The use of GIS in radiation monitoring. In *GIS 93* (pp. 213–221). Birmingham: Blenheim.

Johnson, A. A. (1994). Digital flood insurance rate maps: Standards for shared data. In *Proceedings of the eighteenth annual conference of the association of floodplain managers* (pp. 280–285.

Johnson, A. A., & Smith, T. W. (1994). Beyond steady state: FEMA perspective computer programs—their use in supporting NFIP maps. In *Proceedings of the eighteenth annual conference of the association of floodplain managers* (pp. 249–252). Tulsa, OK.

Lanza, L., & Siccardi, F. (1995). The role of GIS as a tool for the assessment of flood hazard at the regional scale. In A. Carrara, & F. Guzzetti (Eds.), *Geographical information systems in assessing natural hazards* (pp. 199–217). Netherlands: Kluwer Academic.

Lipschultz, M. S. (1988). Application of floodplain management by local government using GIS technology. In *Proceedings of the twelfth annual conference of the association of state floodplain managers, special publication 19* (pp. 321–348). Nashville, TN: Natural Hazards Research and Applications Information Center.

Mather, M. (1993). Maps in action for protecting Trinidad and Tobago from disasters. In P. A. Merriman, & C. W.A Browitt (Eds.), *Natural disasters: protecting vulnerable communities* (pp. 365–373). London: Thomas Telford.

Mercado, A. (1994). On the use of NOAA's storm surge model, SLOSH, in managing coastal hazards-the experience in Puerto Rico. *Natural Hazards*, *10*, 235–246.

Morrison, M. (1996). *Exercise 'Mkattack'*. Queensland State Counter Disaster Organisation.

Nagle, J. A., Ochs, E. S., Bruzewicz, A. J., & McKim, H. L. (1995). *Development and application of a spatial database for emergency management operations*. Hanover, NH: Department of the Army, Cold Regions Research and Engineering Laboratory.

Newkirk, R. T. (1993a). Extending geographic information systems for risk analysis and management. *Journal of Contingencies and Crisis Management*, *1*, 203–206.

Newkirk, R. T. (1993b). Simulation for risk analysis: a challenge for GIS. In J. D. Sullivan (Ed.), *International emergency management and engineering conference* (pp. 62–65) Society for Computer Simulation.

Newsom, D. E., & Mitrani, J. E. (1993). Geographic information system applications in emergency management. *Journal of Contingencies and Crisis Management*, *1*, 198–202.

Oliver, J. (1979). *Wind and storm hazards in Australia*. Natural Hazards in Australia (pp. 136–142). Canberra.

Rayner, S. (1992). Cultural theory and risk analysis. In S. Krimsky, & D. Golding (Eds.), *Social theories of risk* (pp. 83–155). Westport: Praeger.

Robson, C. (1993). *Real world research*. Cambridge: Blackwell.

Rosenfeld, C. (1994). Flood hazard reduction: GIS maps survival strategies in Bangladesh. *Geo Info Systems 1994*, May, 31–37

Salter, J. (1995). Disasters as manifestations of vulnerability. *The Australian Journal of Emergency Management*, *10*(2), 9–10.

Schwarz, B. K. (1989). Ambulance dispatch: topics surrounding a real-time application (pp. 824). In *GIS/LIS 1989*.

Schweizer, D. M., & Goodchild, M. F. (1992). Data quality and choropleth maps: An experiment with the use of color. In *GIS/LIS* (pp. 686–699). San Jose, CA.

Shackley, S., & Wynne, B. (1995). Integrating knowledges for climate change. *Global Environmental Change*, *5*(2), 113–126.

Smith, D. I., & Greenaway, M. A. (1994). *Tropical storm surge, damage assessment and emergency planning: a pilot study for Mackay, Queensland*. Australian National University: Centre for Resource and Environmental Studies.

Spring, G., & Douglas, B. (1995). A new era for Victorian emergency services call taking and dispatch. In *AURISA 95* (pp. 79–82). Melbourne: Australasian Urban and Regional Information Systems Association.

Todd, P. (1995). Process tracing methods in the decision sciences. In T. Nyerges, D. M. Mark, R. Laurini, & M. J. Egenhofer (Eds.), *Cognitive aspects of human–computer interaction for geographic information systems* (pp. 77–96). Dordrecht: Kluwer.

Ventura, S. J. (1989). Framework for evaluating GIS implementation. In *GIS/LIS* (pp. 825–836).

Vermeiren, J. C., & Watson, C. C. (1994). New technology for improved storm risk assessment in the Caribbean. *Disaster Management*, *6*, 191–196.

Von Braun, M. (1993). The use of GIS in assessing exposure and remedial alternatives at Superfund sites. In M. F. Goodchild, B. O. Parks, & L. T. Steyaert (Eds.), *Environmental modeling with GIS* (pp. 339–347). New York: Oxford University Press.

White, G. F. (1945). *Human adjustment to floods*. Chicago: The University of Chicago.

Wisner, B., & Henry, R. L. (1993). Disaster vulnerability: scale, power and daily life. *GeoJournal*, *30*, 127–140.