INTEGRATED AND INTERACTIVE RISK ASSESSMENT PLATFORM FOR WELLINGTON, NEW ZEALAND

Jim COUSINS[1], David HERON[2], Steven JENSEN[3], Michael KOZUCH[4] And John SAVAGE[5]

SUMMARY

Wellington, the capital of New Zealand, is at risk from many hazards. Earthquakes pose the greatest threat. Recognising these risks, Wellington city's Emergency Management Office has commenced an all-hazards programme which promotes risk reduction, community readiness, response co-ordination and disaster recovery. At the heart of this work is risk assessment.

The *Integrated Risk Assessment Programme* is designed to use Geographic Information Systems to illustrate various aspects of hazard impacts, with the twin goals of enhanced communication of risk and greater precision in the formulation of policy options. This project provides a more holistic view of the consequence of various approaches to hazards. Practical techniques, utilising the most up-to-date science and technology, are used to incorporate the latest information into a comprehensive system.

Project goals are as follows:

Evaluate the level of risk resulting from interactions among natural, built, and social environments.

Create an interactive platform for the risk assessment model so that parametric analyses and other sensitivity tests can be performed to evaluate the effect various mitigation strategies, options, and policies may have on risk reduction.

Provide results in a format that Council and other organisations can use to support policy recommendations.

Increase community awareness of relationships between hazard and risk through development of an accessible interactive resource on the Internet.

INTRODUCTION

While the first half of the 20th century was characterised by a redistribution of wealth and the latter half by a redistribution of power, the first part of the 21st century may be characterised by a redistribution of risk. The reasons for this are clear: about 80% of a world population of six billion are living in metropolitan areas. Many of these swelling urban areas are vulnerable to natural and technological disaster, with people continuing to settle in marginal areas. Recent disasters have demonstrated how brittle our cities have become, with vulnerable populations at increasingly higher levels of risk despite advances in our understanding of disaster issues.

The global upsurge in urban growth is compounded by the increasing complexity and interdependency within the infrastructure and economies supporting these communities. Given this complexity, managing growth is a

[1] *Institute of Geological and Nuclear Sciences, New Zealand (j.cousins@gns.cri.nz)*
[2] *Institute of Geological and Nuclear Sciences, New Zealand (D.Heron@gns.cri.nz)*
[3] *Wellington Emergency Management, New Zealand (steven.jensen@wcc.govt.nz)*
[4] *Institute of Geological and Nuclear Sciences, New Zealand (M.Kozuch@gns.cri.nz)*
[5] *Consulting Economist, New Zealand (jsavage@xtra.co.nz)*

difficult task as city planners, risk managers, and others are confronted with the need to build more resilient and sustainable communities.

THE PREDICTABLE NATURE OF DISASTER

"Many disaster losses… are the predictable result of interaction between the three major systems: the physical environment, which includes hazardous events; the social and demographic characteristics of the communities that experience them; and the buildings, roads, bridges, and other components of the constructed environment. Growing losses extend from the fact that …these systems - and their interactions - are becoming more complex with each passing year." (Milletti, 1999)

Each of these sub-systems, the natural, built, and social environments, is vulnerable to the increased strain that comes with extraordinary growth, as well as the complex interdependence of the urban environment. Disaster tends to exploit that strain and interdependence. However, if we can understand disaster better through holistic modelling of the interdependence of sub-systems, we can focus our efforts at reducing risk.

To manage growth effectively a common platform is required for integrating and analysing our knowledge of the natural, built and social environments. This should be done in a way that enables forecasting of the effects of various changes, providing a holistic view of the cumulative impact of these changes. In this way we are able to make informed decisions for our future.

There is a vast amount of scientific literature and reports that have addressed the disaster problem in Wellington. While scientific research is critical to advancing our understanding of phenomena, compilation of all the background material into useable forms is another problem altogether.

GEOGRAPHIC INFORMATION SYSTEMS

In Wellington, we are exploiting the power of Geographic Information Systems (GIS) by integrating data on the natural, built, and social environments to generate new information based on the interaction between a multitude of layers. The project reinforces how interconnected and interdependent our communities truly are.

Spatial information provides another dimension over traditional reporting to search for patterns in data. Animation allows us yet another dimension to view the evolution of these patterns. Each time we add another dimension to our capacity to view or utilise data, the efficiency of these systems over conventional means increases exponentially.

As technology continues to evolve we will find new ways to manipulate or create data. The process then becomes a feedback loop. The technology will push the data and that will push the technology further still.

This provides us with a range of possibilities for modelling risk. For example, economic recovery from disaster is critical for our city. With GIS we can spatially model the economic impact of disaster, with a view to identifying strategic points which require mitigation now for the economy to remain robust following a disaster.

MAKING GOOD DECISIONS FOR THE FUTURE

"Mitigation, as a primary strategy for risk reduction of natural and technological hazards, requires the careful design and implementation of an information infrastructure to support interorganisational decision making and coordination of action. The design of appropriate information infrastructure necessarily includes both organisational and technical components, each reinforcing the other to support a more flexible, adaptive approach to the reduction of risk and response to disaster. Such an information infrastructure represents a sociotechnical system, in which computers, individuals and organisations interact to create a decision support system for practicing managers." (Comfort, 1999)

Computer programmes and the science of modelling have taken us a step further in understanding field data. However, this understanding still falls short of delivering useful information to a large audience. Through the use of GIS, we can integrate a vast array of scientific data on a common platform that is used by a broad spectrum of individuals or industries.

"Technology is transforming our existence in profound ways, and the pace of change is speeding up, not slowing down" (McKenna, 1997). Business clients and the public at large want …*more* control, …of *more* information,

… in *less* time. The digital age coupled with the advent of the Internet is pushing every aspect of our lives into real-time delivery systems. These real-time systems will become increasingly crucial to normal business and government operations where planning or response is involved.

GETTING SCIENCE TO WHERE IT IS NEEDED

Planning for crisis situations requires additional steps that include cutting-edge scientific input. To accomplish this Wellington City Council is in partnership with the Institute of Geological and Nuclear Sciences to develop an all-hazards approach to risk management for the city. The first two phases of the project focused on the development of the base system and associated data sets. The third phase focuses on developing user-friendly interfaces so that this information can be easily accessed through the Internet and other appropriate media. Also included in the third phase is the development of decision trees and links that help a user identify options for mitigating and/or preparing for hazards that have been identified for particular locations.

Ultimately a wide range of users at different levels of access will be able to use the system. With Internet tools, users will be able to create their own maps and scenarios to rapidly assess the status of an event or design the future of the city for “what-if” events. GIS married with the Internet provide the optimal combination to exploit the power of spatial data based upon the best scientific input.

KEY COMPONENTS OF THE PROGRAMME

The prime hazard considered was earthquake shaking, with our default model being a magnitude 7.5 event on the Wellington fault. Consequent hazards included landsliding, liquefaction, tsunami inundation, and post-earthquake fire spread. The screen below depicts the isoseismals from a preselected earthquake and the choice of effects that the user could model.

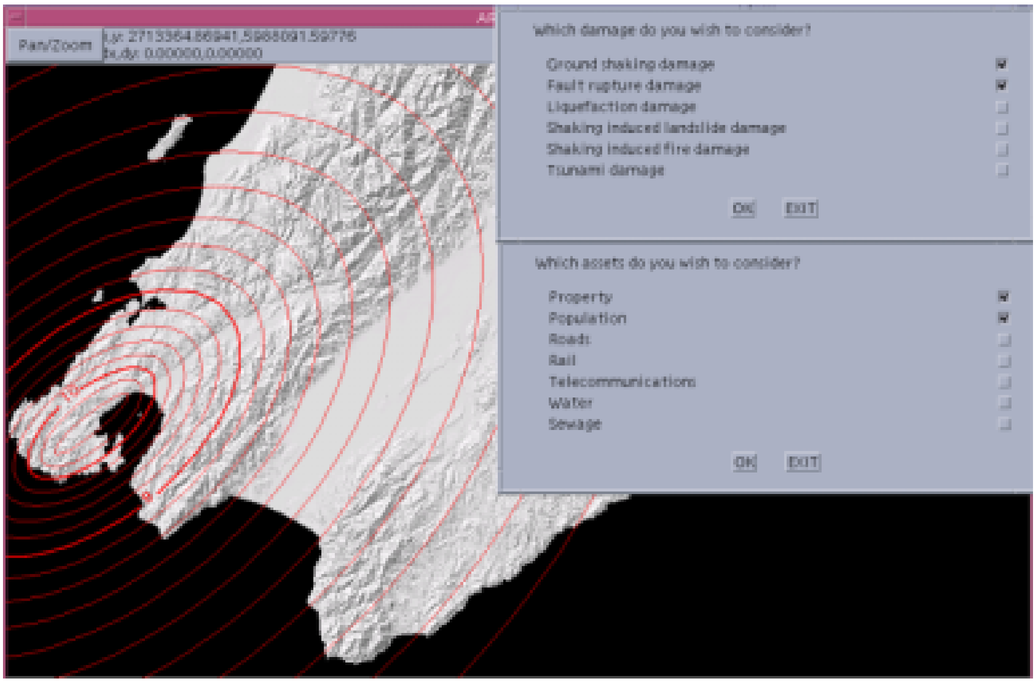

Figure One: Sample GIS screen showing options to model

In a related but largely stand-alone pilot study a model for indirect economic losses was also developed. This required development of linkages between the destruction of assets and business activity. These activities are described below.

GEOGRAPHIC INFORMATION SYSTEMS

The platform used was the GIS software package ARC/INFO, which enabled us to store, manipulate and link the many items of data needed for a useful model. The acquisition of much of the input data can nowadays be regarded as relatively conventional, for example inventories of assets, and susceptibility maps for landsliding, liquefaction and tsunami inundation, though the difficulties of ensuring reasonable levels of completeness and accuracy should not be underestimated.

DATA

The biggest challenge facing any city or community is to generate accurate digital information from what is known about the city and the hazardscape. This is often the most tedious and time-consuming step. Once in an electronic form, however, this information can be manipulated or reformatted to meet the changes in the supporting technologies. As new technologies emerge, the backbone of our system will evolve to meet these changes.

Building value, materials, height, and age information from a valuation database was matched with parcel polygons from a property database to provide a geographic reference for each building. The materials, height, and age data were then used to classify the buildings into 34 classes representing the building's structural strength. Population data, available at the mesh block level, was used to provide an estimate of the number of people in each structure.

Model implementation

Implementation of the model within ARC/INFO was relatively simple. Standard earthquake attenuation equations (Dowrick and Rhodes, in press) define polygons of equal ground shaking intensity. A spatial overlay of building data on these intensity polygons allows damage and casualty ratios to be calculated from the building strength class, building value, building population, and intensity of shaking on a building by building basis.

Priority was placed on fine-tuning the model to ensure efficient operation. The building database contains some 45,000 points, for which up to 14 calculations are required. Current run times are approximately 5 minutes.

Building Performance

Good data on buildings is crucial to the model because buildings are expected to be the cause of most of the losses and most of the casualties in earthquakes affecting Wellington. For each of the buildings we need to know the location, size and height, construction (form, materials, age, quality), value and number of occupants. Such a database does not exist. We used data from the former Valuation New Zealand as a base and allocated as much effort as we reasonably could to filling gaps and removing ambiguities. As we did not want to be in a position of having to maintain databases, our effort was directed toward automating the procedures that were required to adapt existing databases for our needs.

Losses were estimated by multiplying values and appropriate damage ratios, where the damage ratio D_r at any given intensity is defined by

$$D_r = \frac{\text{Cost of material damage}}{\text{Value of property at risk}}$$

We took damage ratios from two sources, (i) measurements of earthquake losses for New Zealand buildings made by Dowrick and co-workers (e.g. Dowrick and Rhoades 1997), and (ii) estimates of vulnerability of property in the USA made by a panel of experts (Rojahn, 1985). We believe that the Dowrick and Rhoades results are more reliable than those of Rojahn, but the Rojahn estimates cover a much wider range of asset types. Both sources gave relatively similar values for commercial and domestic buildings at an intensity of MM9 and so we used the MM9 values as benchmarks. The Dowrick and Rhoades results were then used to define the variation of D_r with intensity and the Rojahn results to differentiate between the various types of building.

Where known, specific information on the vulnerability of earthquake prone buildings was incorporated. Collapse probabilities for the various classes of building in Wellington, and subsequent death, serious injury, and moderate injury rates, were based on the results of Spence et al (1998).

Some indicative figures for shaking of intensity MM10, and for the best and worst types of construction found in Wellington, are as follows:

Building type	Timber frame	Unreinforced Masonry
Damage ratio	0.2	0.8
Collapse rate (more than 50% loss of volume)	0.0015	0.1
Death rate (fraction of occupants)	0.000013	0.014
Serious injury rate (fraction of occupants)	0.000004	0.009
Moderate injury rate (fraction of occupants)	0.00015	0.015

The screen below depicts aggregate building damage by suburb. This can be viewed at the individual property level or at the macro level.

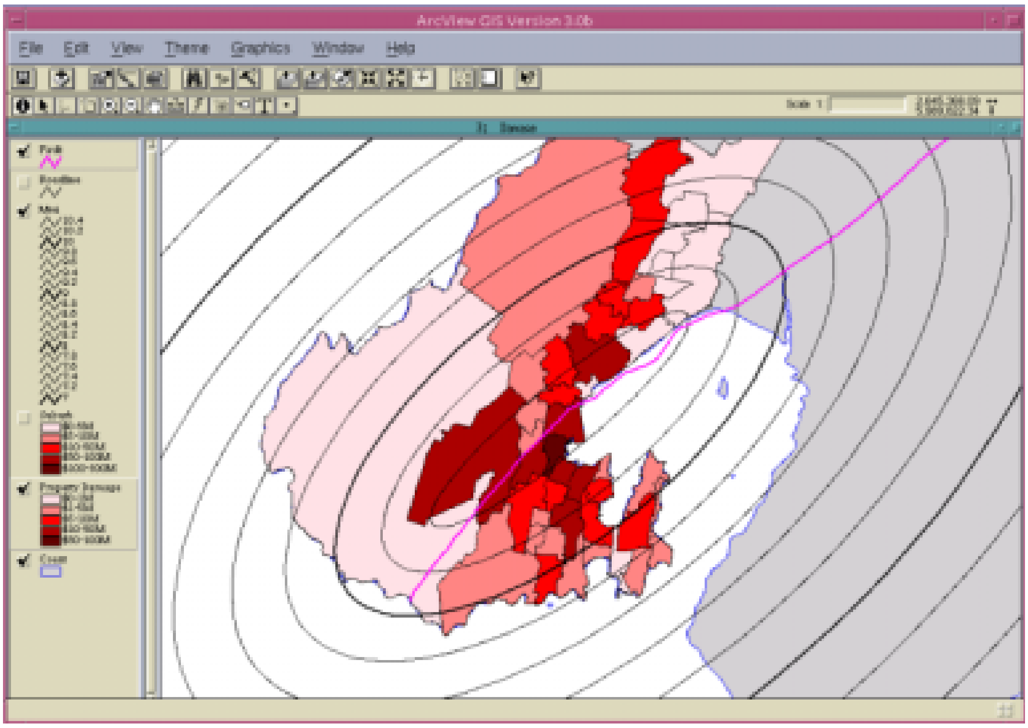

Figure Two: Building damage by suburb

FIRE MODELLING

Possibly the most novel part of the project is a module for estimating and visualising the spread of post-earthquake fire. This required spatial information about buildings, vegetation of varying degrees of combustibility, and a terrain model. The very important variable of wind was accommodated in the form of a user-controllable variable. The screen below depicts fire damage resulting from random ignitions with the fire left to burn to existing breaks in the available fuel.

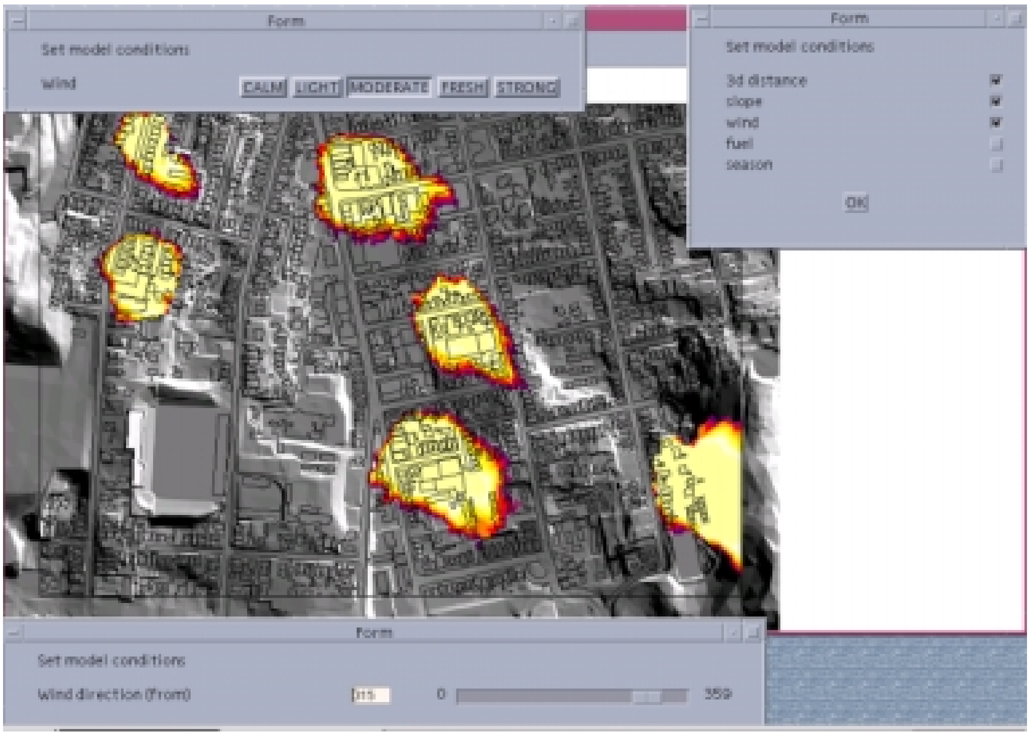

Figure Three: Fire following earthquake represented by light areas

Fire spread models for bush land fire spread are available from North America, but no suitable model was available for the urban and urban fringe environments. The model must interface with ARC/INFO to allow results to be passed between the Fire Model and the Earthquake Model. This data flow is bi-directional (earthquake damage alters the fuel characteristics of buildings and feeds into the fire model, fire alters the total damage resulting from the earthquake and feeds into the damage model).

Fire simulation systems combine a fire prediction model with a fire spread technique. A physical-statistical fire prediction system (based on available physical fire theory supplemented with statistical correlation) and a cellular automaton spread technique (in which the landscape is modelled as a lattice of cells, each with a set of values representing the physical environment) have been selected as the favoured approach. A simple system has been developed and has demonstrated that it is possible to run a fire spread simulation within ARC/INFO Grid at a speed that enables models to be run in less that two minutes. This research code displays the results as images of burnt and burning areas at specified time intervals.

MODELLING ECONOMIC LOSSES

The objective of this component of the project was to estimate the economic consequences of a major Wellington earthquake. Doing so raised a number of complex modelling issues. In particular, there was a need to consider the following issues:

- How to link direct economic losses (destruction of physical capital, loss of life) with indirect losses (i.e. the flow-on effects of damage to economic lifelines). The downstream and upstream effects running from damaged businesses to undamaged ones, the diverse economic effects of rebuilding activity, and the general economic disruption caused by the quake.

- How to make these economic linkages within a spatial (GIS) framework.

It became clear early that the complexities of the modelling exercise meant that a staged approach was required, with the first stage being kept as simple as possible.

The simple methodology adopted for stage one was as follows. A national, 50 industry input-output (IO) table was used to derive a regional table for Wellington. An IO table comprises a data matrix that allocates the outputs from different industries as either inputs to other industries, exports or “final consumption” by households. In doing so the IO table captures the complex interrelationships between different sectors of the economy. IO tables are very valuable tools in tracing the upstream and downstream effects of natural disasters.

This in turn was converted to spatial data by taking information on the number of employees by “area unit” and by industry as proxies for output by industry by location. Meshblocks are the smallest geographical unit for which damage data is available. Area units are the next largest geographical units. Employment data is currently only provided at the area unit level. Property damage ratios at the meshblock level (imported from the GIS model) were then aggregated up to area unit values and aggregated by industry to obtain factored-down employment totals. These in turn were used to factor down industry output and generate a vector describing the *maximum* output achievable by each sector post-quake.

Whether a particular sector achieves this maximum level of output depends on whether there are bottlenecks in supply from other sectors. The IO framework allowed these bottlenecks to be identified and then assumptions made about the extent to which firms required “intermediate imports” from outside the local region in order to maximize their output. In one alternative scenario, it was assumed no imports were readily available and output was reduced across all industries by the same proportion as the worst hit sector.

The IO framework also allowed us to estimate whether firms running at their new post-quake capacities could match household demand for goods and services. To the extent they could not, assumptions were made about imports into the region by households. Having estimated whether household demand was being met, estimates were made of the proportion of GDP that is available for investment and exports.

A number of developments are planned for the next stage of the economic modelling. In particular, it is intended that the economic effects of lifeline damage will be modelled more explicitly.

CONCLUSIONS

The Integrated Risk Assessment is a powerful tool to support the building of resilient communities. However, it is only a tool and must be oriented around real needs of those who are trying to bring about meaningful change. That change happens through a long and difficult process, with many organisations involved at various levels. To be effective the Integrated Risk Assessment needs to be accessible, relevant, and provide a holistic view. Perhaps most importantly it should present a realistic view based upon the best information, without seducing users into believing we understand more than we in fact do, for disaster has a way of exposing our ignorance…and arrogance.

REFERENCES

Comfort, Louise (1999) The Impact of Information Technology upon Disaster Mitigation and Management, University of Pittsburg, Pennsylvania

Dowrick, D.J. and Rhoades, D.A. (1977) “Inferences for design, insurance and planning from damage evaluation in past New Zealand earthquakes”, *Journal of Earthquake Engineering, 1(1), pp77-91.*

Dowrick, D.J. and Rhodes, D.A. (In press) Attenuation of Modified Mercalli Intensity in New Zealand Earthquakes.

McKenna, R. (1997) Real Time, Harvard Business School Press, Boston, Mass.

Milletti, Dennis S. (1999) Disasters by Design: A Reassessment of Natural Hazards in the United States, Joseph Henry Press, Washington D.C.

Rojahn, C., Principal Investigator and expert panel (1985) “Earthquake Damage Evaluation Data for California”, *Report ATC-13, Applied Technology Council, Redwood City, California.*

Spence, R.J.S., Pomonis, A., Dowrick, D.J. and Cousins, W.J. (1998) “Estimating human casualties in earthquakes: the case of Wellington”, Proceedings, Sixth SECED (Society for Earthquake and Civil Engineering Dynamics) Conference: *Seismic Design Practice into the Next Century, Oxford, UK, March 26-27: pp 277-286*