Regional RiskScape: A Multi-Hazard Loss Modelling Tool

Andrew King, Jim Cousins, Dave Heron, Iain Matcham, Robin Pringle
GNS Science Email: a.king@gns.cri.nz

Rob Bell, Stefan Reese, Jochen Schmidt, Roddy Henderson
NIWA Email r.bell@niwa.co.nz

Abstract

New Zealand has experienced community damage from every conceivable natural hazard. Events such as earthquake (both shaking and fault rupture), volcanic activity (both near-field effects and distil ash deposition), tsunami, flooding, storm (wind, snow/ice and tidal surge) and landslide. Damage to buildings and inventory along with personal injury and loss of life have resulted. While advances have been made over the past few decades in understanding many of these phenomena, only recently has sufficient knowledge been acquired to enable some rational probabilistic models to be developed to quantify the recurrence of some of these hazards and, through an appreciation of the fragility of the current inventory, to ascertain the community risk.

The path towards the development of RiskScape New Zealand is subject of this paper. RiskScape New Zealand is a national multi-hazard impact model that presents relative risks and community exposure to a range of natural hazards. The prototype currently under development will consider the impact of five of the most commonly encountered natural hazard (including earthquakes and tsunami) on three representative New Zealand communities. The model evolution recognizes the conflict between the GIS presentational environment expected by typically non-technical end users (such as emergency management officials and community planners) and the need for a computationally efficient environment that will ensure processing time for large inventory datasets remains acceptably short.

The development of the RiskScape New Zealand model has been underway for three years of its four year proof-of-concept phase. The framework, the range of natural hazards and the communities targeted for the prototype study have been finalized. Classification of the inventory datasets into their various fragility subsets is underway. The linkages between damage state and repair/disruption are being developed for each of the hazards within the study, within initial focus on earthquake, tsunami and flooding.

Keywords: Earthquake hazard, Tsunami hazard, Loss modeling, Societal impact, Disaster planning, Post Disaster recovery.

Introduction

New Zealand has an evolving landscape that results in an exposure to a wide variety of natural hazards. The extremes of weather and geological forces that create its unique character also present many hazards, including earthquakes, volcanic eruptions, tsunamis, storms, floods and landslides. River flooding is the most frequent and costly peril in New Zealand (Smart 2006, Te Ara 2007), but over longer periods, earthquakes and tsunami are expected to produce substantial damage and potentially some loss of life e.g., 1931 Hawkes Bay earthquake (Wright 2001). Further, the consequences of all weather-related hazard events are likely to be compounded by the effects of global warming. In particular, the major increases in risk will be in coastal areas (due to sea-level rise and associated intensification of waves and storms) and river/urban inundation (due to intensification of rainfall) (NIWA, 2007).

Increasingly, decision makers such as emergency managers (response planning) and land-user planners (mitigation measure) are expected to make decisions based on quantitative information as to possible consequences and the risks associated with different hazards (Blong 2003, Durham 2003, Grünthal et al. 2006). Only with such information are they in a position to compare the impacts across the different hazards before making investment decisions on risk reduction for their region. For example, a recent overview of the national tsunami risk has estimated that the potential for casualties and damage is comparable with the national earthquake risk given the same exceedance probability (Berryman 2005).

In the past, risk management has been mostly reactive. RiskScape is a new tool, being developed jointly by the National Institute of Water and Atmospheric Research Ltd (NIWA) and the Institute of Geological and Nuclear Sciences (GNS Science), with the aim of simulating regional scenarios in advance, and producing estimates of damage in dollars and likely casualties (Bell & King 2006, Schmidt et al 2007). It will provide informative support for decision makers.

2. RISKSCAPE FRAMEWORK

The prime goal is to produce an easy-to-use decision-support tool that converts hazard exposure information into likely consequences for a region. These consequences may be related to damage and replacement costs, casualties, disruption and number of people displaced or affected by a severe natural occurrence. The consequences for each region are to be presented on a common, computer-based platform across a range of natural hazards. Proposed mitigation measures can be modelled by altering inventory vulnerability functions and the resulting changes to risk profiles evaluated by re-imposing the hazard impacts. Such an approach can then form the basis of prudent planning and prioritized risk-mitigation measures that link directly to the severity of the risks (Schmidt et al 2007).

RiskScape operates from a sequence of drop-down options. First, the zone of influence of a particular hazard is defined and its local intensity and recurrence interval established. Then the impact of events of various intensities can be calculated by overlaying the hazard exposure for each event over built-environment inventories and demographic profiles of the people exposed to such event (i.e. the receptors).

An essential component in estimating losses is an inventory of material and non-material assets that may be impacted by an event. Thus, an inventory of buildings, occupancy rates, infrastructural assets and people is a core backbone of any loss-modelling tool. It provides critical input to several stages of the risk calculation (see Figure 1). Dealing with different types of hazards and numerous assets and land uses (e.g., agriculture) requires a huge amount of information, particularly about the characteristics of the assets at risk e.g., construction characteristics of buildings, routes for utilities such as water supply, sewerage, road and power, demographic and business information. To be effective, each inventory element requires both geo-referenced coordinates sufficient to locate that element and sufficient attribute definition to enable that element to be assigned to its appropriate vulnerability class. A comprehensive national database on building and infrastructure attributes does not exist in New Zealand. Existing building valuation databases were supplied by Quotable Value NZ Ltd and provided some basic attributes. During the development phase of RiskScape, different means of determining and assigning other essential default attributes where evaluated to fill in those gaps where data doesn't exist. However, there are still various attributes, e.g. building floor height, which is relevant to flood water damage to buildings, about which no handy information exists. Thus, sample field surveys were undertaken and new techniques such as satellite imagery or laser-scanning (LiDAR) used to get the necessary information about the elements at risk. For people, data from the 5-yearly census, provides a nationally consistent and reliable dataset for a meshblock (an area with about 50-150 houses).

Distributing the hazard intensity across the affected region is undertaken with the hazard definition module and is the second cornerstone of the RiskScape tool. Riskscape employs two alternative approaches when defining hazard impact distribution. The first and more versatile approach is to embed a computation module within the tool which computes the intensity of the hazard at each point to which an asset is assigned. This is used for earthquake evaluation and also for distal ash distribution. The second alternative is to pre-compute the distributed hazard intensities and install the results into RiskScape using a raster or vector model of the effected area. This approach is used for flood, wind and tsunami impact determination. In the latter cases, use is made of sophisticated computer models that simulate the hazard (e.g. the flow of floodwaters over floodplains or streets; tsunami overland flow). Where data is available from historical events, this is used to validate the resulting models. To allow the end-user to analyze and compare the risks and consequences from different hazards, a probabilistic approach is used. However, particular scenarios or historic events can also be simulated.

The third cornerstone is the suite of fragility/loss modules which relate the probable damage or loss experienced by each asset class when subjected to different intensities of action from each hazard effect (i.e. the depth/velocity combination of flood water that would result in losses equivalent to 25% of the building replacement cost). Vulnerability or fragility curves are the most common way to estimate hazard-related damages because there is usually a correlation between monetary losses, the damage state and the hazard intensity. However, understanding these correlations and associated uncertainties for the range of building and infrastructure characteristics present in New Zealand is one of the major challenges of the RiskScape project.

But the risks are much wider than those of direct damage to our built environment. RiskScape is also being developed to include impacts on people and society, initially addressing the risk of casualties or injuries and potential numbers of people affected. The economic effects of a major disaster can be significant depending on where the boundaries of the analysis are drawn. If a national perspective is taken, the economic effect of the lost gross domestic product (GDP) would normally be small. However, if the analysis is confined to the affected area, the economic effects can be severe, although some sectors like the construction/building sector often benefit. Hence, RiskScape will not only focus on direct damage to our built environment but also addresses the impact on people's lives and indirect damage. That provides planners and emergency managers with a comprehensive and detailed overview of possible consequences and enables them to prepare and develop mitigation strategies in advance.

Conceptually, this process from hazard to risk is relatively straight forward, but application to real-world situations is problematic, with inherent difficulties in obtaining and linking good-quality inventory and demographic datasets and comparing hazards with vastly different recurrence intervals and source mechanisms. These challenges are being met by the development of a Regional RiskScape Model.

The key principles built into the RiskScape system are:

- Primarily intended for applying to community impacts rather than to impacts on individual properties or people.;
- Usable by emergency managers and planners who may have little knowledge of the science and engineering aspects of natural hazards;
- Develop the computational "engine" using open-source software with limited GIS-like capability to avoid expensive licensing arrangements, but still provide input/output processing on a GIS platform;
- Designed as stand-alone software to be functional during a major hazard event and not be reliant on a server.
- Capability to implement external asset databases, models or loss curves. This provides the end-user with flexibility to implement RiskScape into their existing environment rather than being forced to switch to a completely new system.

- Results on the consequences (damage, disruption, casualties) will primarily be produced for aggregated areas (e.g., typically census meshblocks of between 50 to 150 houses or other aggregation units that the end-user may prescribe). Within RiskScape the loss computations are undertaken at an individual asset level, but such individualised results are restricted to be available only to the owners of the inventory data.
- Where possible provide truly comparable losses & casualties from different natural hazards for specified exceedance probabilities (or return periods), as well as the ability to simulate losses from historic or prescribed scenarios;
- Ability to import directly the modelled hazard exposure fields from previous runs of sophisticated dynamic models (that may take several hours to run) or to compute these fields internally where simpler attenuation models are possible e.g., earthquake shaking;
- Concerted effort to track uncertainties at all stages of the processing that turns a hazard exposure into losses;
- Working alongside regional and local government partners over the 4-year project to provide a fit-for-purpose tool that is practically useful in risk-reduction decision making;
- Fast computational system that enables the system to also be used during a major hazard event as it unfolds or as a simulated exercise by emergency managers.

The overall concept of the Regional RiskScape system is shown in Figure 1.

For the initial development phase (4 years), we are trialling the system with three regional/local government partners (centred on Westport, Napier & Hastings, Christchurch) which cascade up by an order of magnitude in population. The initial natural hazards being considered are: earthquake, volcanic ash-fall, local and distant tsunami, storms (wind only), and river flooding. However, the software design allows other hazard modules to be added later.

To aid emergency planning and response RiskScape has been developed to ensure that it is compatible and usable with as many end-users as possible. The system is stand-alone with the computational engine developed using open-source software to avoid expensive licence arrangements. Since the majority of possible end-users already use well established GIS software, RiskScape has been developed to allow import and export of data into any existing GIS platform. However, the tool will have basic GIS functionality and allows the end-user to conduct a range of analysis such as filtering the results e.g. where are the areas with more than 25% damage to buildings.

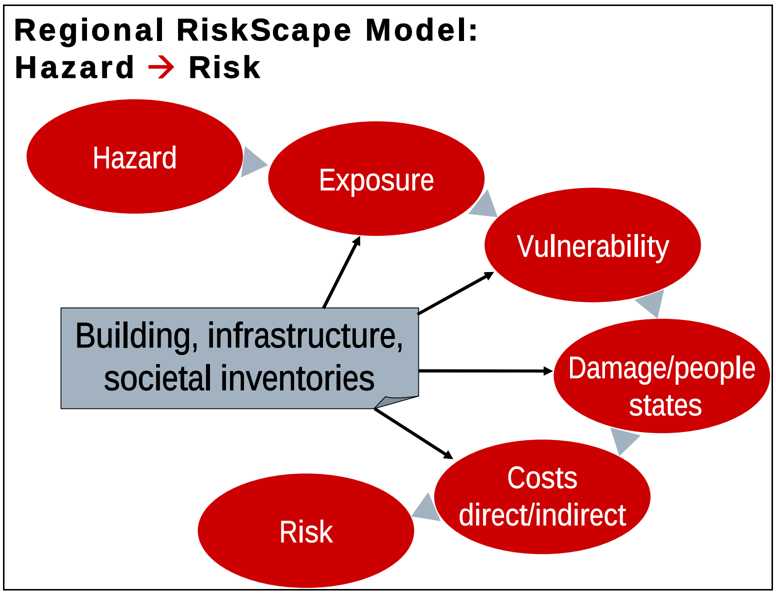

Fig. 1: Flowchart of main modules of the Regional RiskScape tool.

3. APPLICATION OF THE RISKSCAPE SYSTEM

The RiskScape System is built on a modular modelling framework. New hazard, asset, or loss modules can be seamlessly integrated into the running system as new modules (Figure 2). A RiskScape module specification and module builder interfaces have been developed to facilitate this task.

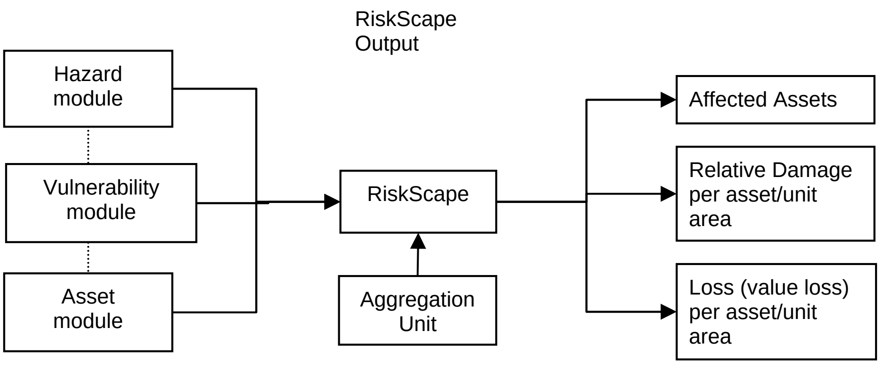

Fig. 2: Components and outputs of the RiskScape system.

The RiskScape user interface guides through a series of sequential risk modelling steps:

1. Choose hazard
   User selects a hazard type, currently implemented: earthquake shaking, severe wind, river flood, tsunami, volcanic ashfall.
2. Choose hazard model.
   Where multiple models exist, the user selects a particular hazard model, implemented for selected hazard type.

3. Define model parameters.
   The Interface queries hazard parameters specific to the selected hazard model, eg. earthquake depth and magnitude, and subsequently displays the selected hazard scenario (Figure 2).
4. Select assets and aggregations.
   The Interface offers assets that are under threat from the defined hazard scenario.
   Aggregations are optional spatial units (for example authority boundaries) for displaying losses on a spatially aggregated level.
5. Select fragility function.
   The user can select a fragility function (= loss model available for the selected combination of hazard and asset.)

Once hazards, assets, aggregations, and fragility functions have been selected, the system computes damage ratio (Figure 3) and expected losses on an asset and aggregation level (Figures 4 and 5).

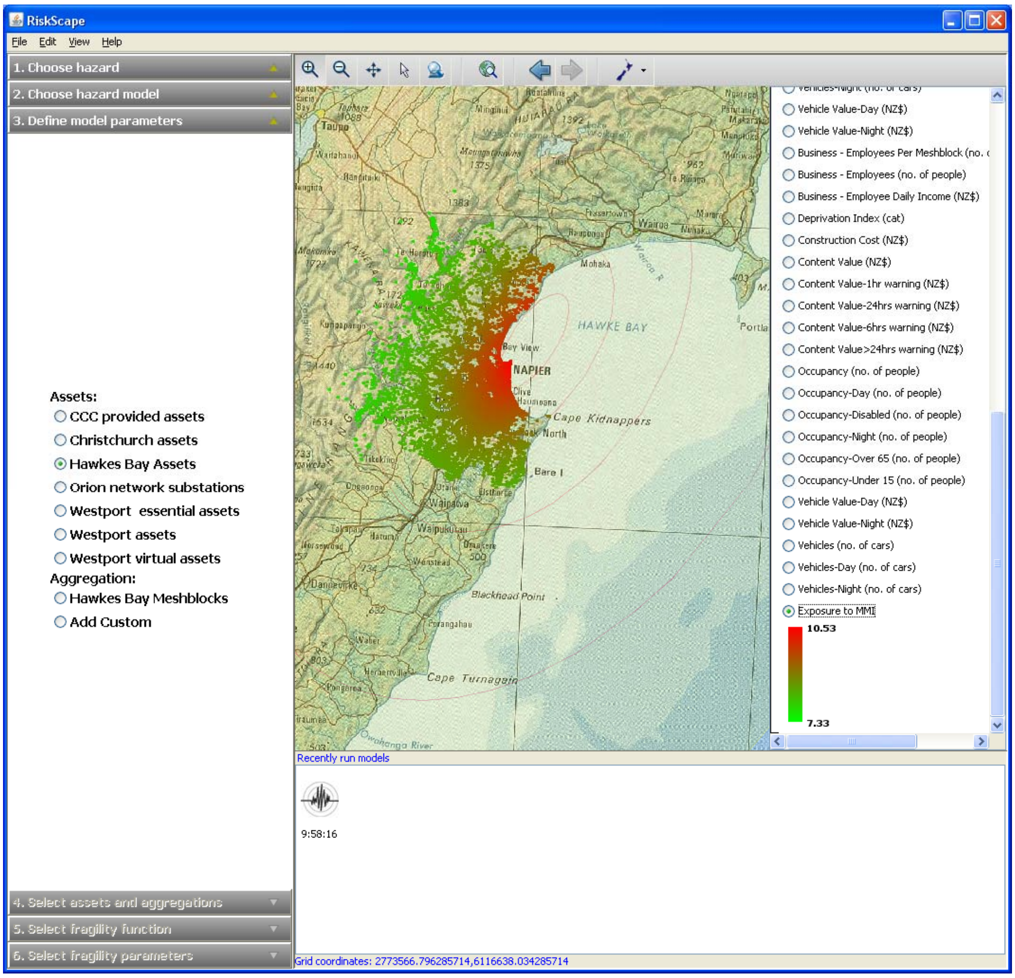

Fig. 3: Example of a simple earthquake scenario applied to buildings in the Hawkes Bay region

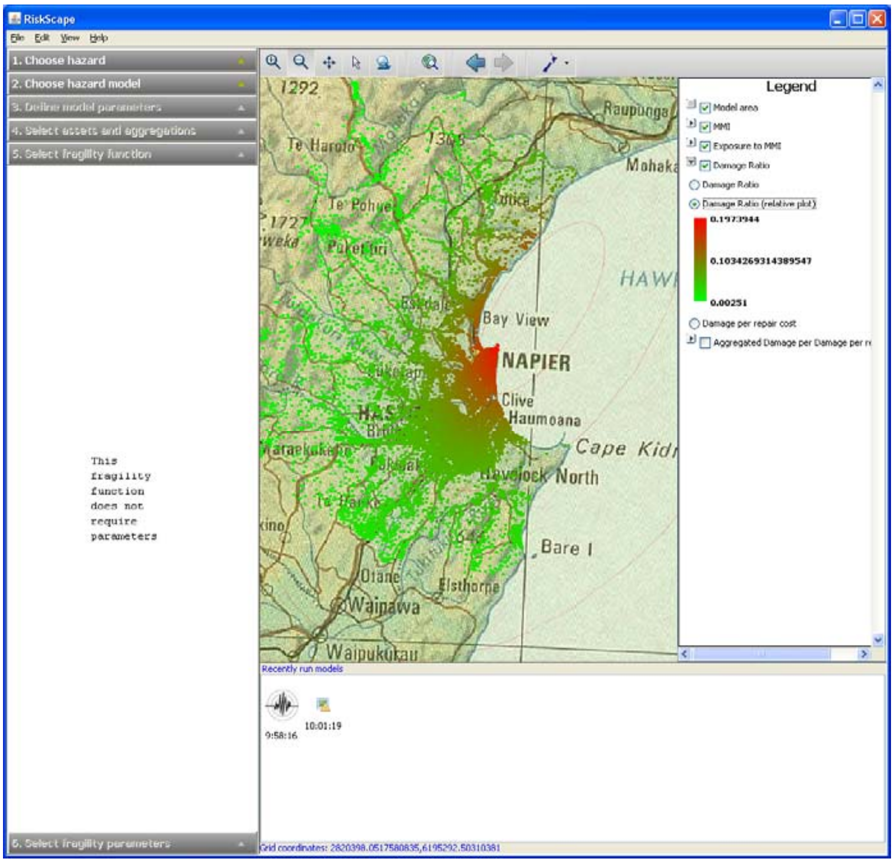

Fig. 4: Map of expected building losses from the earthquake scenario

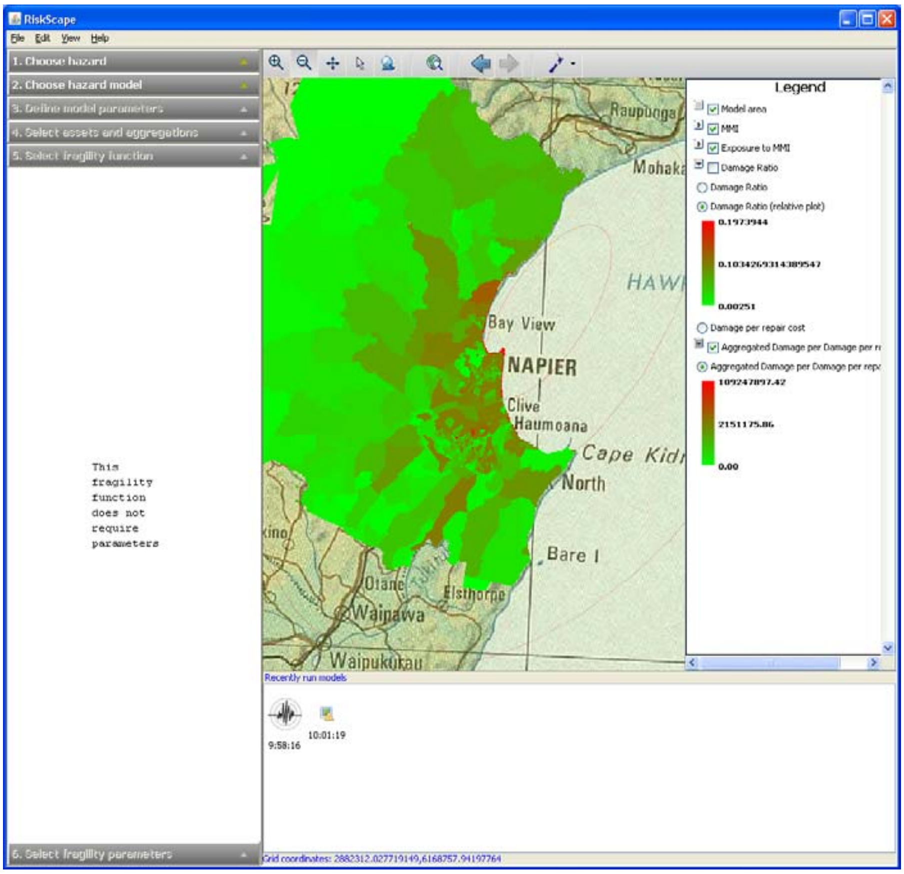

Fig 5: Building losses from the defined earthquake scenario aggregated on a meshblock level

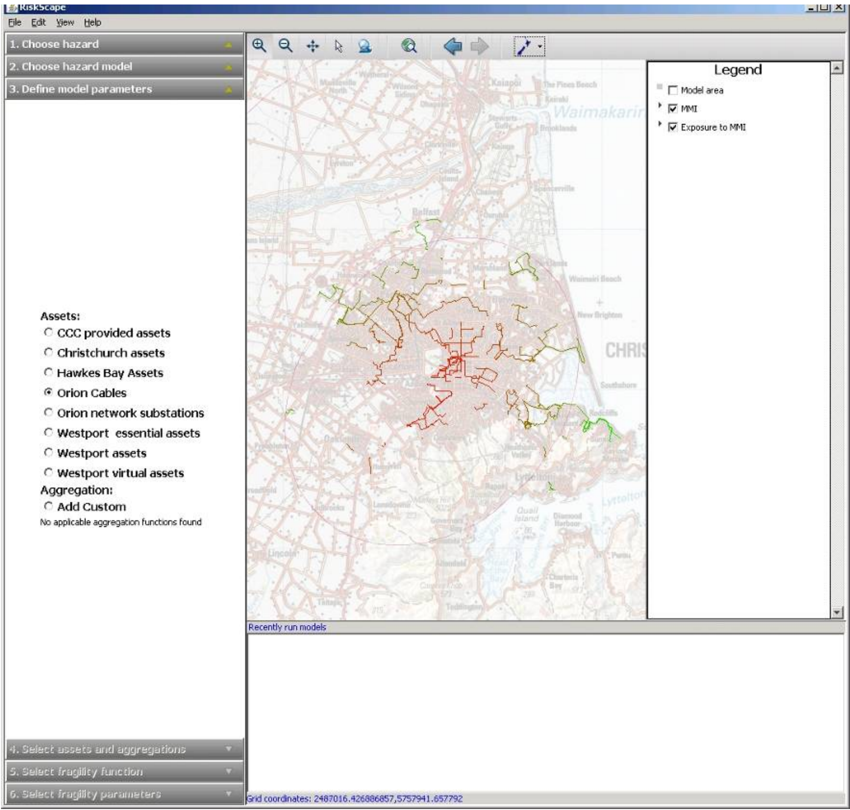

Fig 6: Infrastructure distribution and supply network representation

4. ISSUES AND CHALLENGES

The project was launched in 2004, the first prototype released to our partners in July 2006 and an operational version is expected for winter 2008. While only a default inventory will be available for the three pilot study areas initially, the framework is expected to be established that can apply to all other areas of New Zealand. After 3 years into the project, several issues have emerged that provide some challenges to the development and implementation of a quantitative risk assessment tool:

- Access and availability of building and infrastructure inventory data that have sufficient parameters to assign fragility classes and hence fragility curves and damage states for each natural hazard. An example is the lack of ground-floor elevations for buildings to assess flood and tsunami damage and roof type and % openings data for wind damage. At this stage we have calibrated a floor height relationship using building age classes as a surrogate based on field sampling surveys;
- Accurate modelling of the hazard exposure is a crucial step in the process, particularly for topographically-steered hazards such as floods and tsunami and to a lesser extent wind. A critical element of successful modelling in this context is the availability of accurate

coastal and floodplain topography such as LiDAR (airborne laser scanning) or satellite radar altimetry;

- Each hazard sector uses different ways to communicate risk, probability and uncertainty, so we have an ongoing need to work with our partners to ensure they have results from RiskScape that are appropriate for their intended use in decision making;
- Acceptance of the results including the inherent uncertainties (no matter how grim) by the end users and a means by which they can be assisted in getting public and political buy-in for appropriate and cost-effective risk mitigation measures e.g. the cost-benefit may be higher for earthquake-proofing a critical bridge than adding more height to a stopbank (levee) in a particular area (or vice versa);
- Ongoing maintenance of hazard exposure models & inventory datasets as changes in the built environment occur and revised updates on climate-change projections become available.

5. OUTLOOK

The Regional RiskScape decision-support tool has been through a 3-year development phase. Much has been achieved in firming up the concepts and undertaking preliminary software development through the cooperative effort of two institutes working together. Field experience in sampling building attributes relevant to a wide range of natural hazards has been invaluable in assessing the minimum information required, complemented with the use of more-readily-available surrogates such as building age where possible. Key progress steps now are: a) to use preliminary results of Regional RiskScape to demonstrate to and consult with local/regional government and infrastructure/utility agencies involved in hazard management about how to best streamline the tool and its outputs to suit their requirements; and b) then to proceed to fine-tune and operationalize the tool in the remaining year.

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Author's Biography

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