TEPHRA

KIA TAKATŪ TAHI TĀTOU

June 1996 • Volume 15 • Number 1

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Foreword - John Banks

I was glad when the Prime Minister invited me to take the Civil Defence portfolio in February, on the retirement from Cabinet of Hon Warren Cooper. I expressed an interest in this portfolio which I regard as vitally important. It also has a close relationship with another of my responsibilities, Local Government.

In recent years I have observed the hard work of people in civil defence at a local, regional and national level. The country is served by dedicated workers. However, we have also been fortunate in that the events we have had to cope with have been manageable.

Through television recently we have been reminded of the two most potentially devastating natural hazards: a massive volcanic eruption, and a great earthquake.

Back in 1991, as Minister of Police, I participated in 'Exercise Our Fault', based on an earthquake scenario. That was part of on-going work done on both hazards. Since 1989 studies concentrating on major 'lifelines' have been underway in Wellington and more recently Christchurch.

On 30 May I approved a volcano hazard plan, as part of the National Civil Defence Plan. We have also had studies like that of Sir Somerford Teagle's Task Force and Mr Ian McLean to consider our current ability to prepare for, respond to and recover from events on a large scale. It is valuable to study more closely the chances of devastating natural disasters occurring so that the community at large, as well as civil defence organisations, can take appropriate steps in mitigation and preparedness. That is what this issue of Tephra does.

Civil defence is based on self help and mutual support. This principle operates at individual, community and national level. It applies equally to households and to businesses. I hope that readers of Tephra will apply the principles of good risk management.

Hon John Banks
MINISTER OF CIVIL DEFENCE

Foreword - Paul Officer

RISK MANAGEMENT AND CIVIL DEFENCE

Perhaps to lay people, it is a truism to say that all life is full of risk. Along the way we encounter many uncalculated outcomes, some happy and others adverse. It is often difficult to know which adverse events will prove permanently disadvantageous, since some will lead to innovation and a safer future. Browning's assertion "we fall to rise, are baffled to fight better" may seem over optimistic these days (as it did to some in his) but it contains a truth.

Risk in our context is a way of describing the probability and consequences of a disaster. Risk tries to identify the expected losses from the impact of a given threat to a given vulnerable element over a specified time period. Sir Edward Somers' Committee on nuclear powered ships noted, "It may be helpful to distinguish four main categories of risk: perceived risk, which is the risk as understood by those at risk; acceptable risk, which is a risk level chosen as a limiting requirement by those setting standards and making decisions for society; calculated or estimated risk, which is the figure computed by designers and planners for the risk of failure of something to be built; and real risk, which is the true risk which could only be known if we had access to all that could be known about the situation".

The distinction between perceived and real risk is critical to the work of civil defence. The perceptions of people, even if statistically astray, are major influencers on behaviour and need to be taken into account, both in the presentation of risk analysis and in the formulation of risk management policies.

It may be true that the chance of winning a major prize in some lottery is exactly the same as encountering a great earthquake in a certain time period, but most people seem more likely to "invest" in a ticket than in velcro for the china heirloom on the high shelf. We cannot assume that accurate risk analysis will lead automatically to public understanding and our policies for risk management will need to include educational work.

It is for this reason that I have devoted this issue of Tephra to the subject of risk. It brings together various articles that address risk topics related to our work in the Ministry of Civil Defence. In doing so I hope that the Ministry will contribute in some small way to a process of education on these matters.

The Earthquake Commission, whose chief executive David Middleton has contributed one of these articles, provides a key example in New Zealand of risk management which combines prudent saving against events statistically certain to occur, with public education to reduce the impact of those events, and the calls on those savings.

Janet Gough's article draws attention to a particular vulnerable group, overseas visitors. We wish to encourage people to see New Zealand's attractions including the ski fields, volcanoes and geothermal wonders. But the meteorological and seismic processes which produce the attractions create hazards as well. Collectively we should seize the opportunity to better manage this dilemma.

The clear communication of risk is an increasing challenge. As the Ministry of Civil Defence has been at the centre of the assessment of risk in connection with Mt Ruapehu (described in one of Pat Helm's contributions) so we are working with other agencies of local and central government to improve our understanding of risk concepts. I am confident readers will find this issue of Tephra particularly interesting.

P N Officer
Director
MINISTRY OF CIVIL DEFENCE

FLOODING *Photo by The Evening Post*
In New Zealand the most common natural hazard is flooding. Wellington, 1996.

Integrated Risk Management for Natural and Technological Disasters

by Patrick Helm
Department of the Prime Minister & Cabinet, Wellington

Introduction

Risk assessment has been little used in New Zealand for the management of emergencies and natural disasters. At best it has been regarded as a passive activity to help insurance companies set premiums for coverage of infrastructural damage. This has tended to give an engineering orientation to risk management that does not necessarily accommodate the wider needs of the community.

Yet the techniques now becoming available for analysing and quantifying risk can prevent or minimise disasters, can improve safety, and can markedly reduce societal disruption following disasters. They have much to offer those responsible for reacting to emergencies and dealing with the aftermath.

As New Zealand moves towards improving its national and local systems for emergency management, risk analysis will provide powerful new instruments for managing risks across different sectors, for developing strategies to deal with particular hazards, for allocating resources, and for helping set priorities and standards in dealing with public sector safety issues.

Government Perspective

Government's interest in risk management in respect of dealing with emergencies and natural disasters began about ten years ago. With the transfer of responsibility that occurred through the reforms in local authorities in the 1980s, central government put in place policies designed to encourage more effective safety and loss prevention strategies. These were enunciated, for example, in a set of principles developed for the 1987 Recovery Plan for Natural Disasters which placed considerable emphasis on risk management and mitigation.

The essential idea was that central government would accept shared responsibility for the restoration of damage from natural disasters only if the local authority concerned had done its part to minimise, mitigate, and manage the risk to its assets. The expectation was that local authorities would not simply provide insurance cover, but would seek to protect life and property by managing all the risks they faced. That is, they were expected to take all reasonable steps to reduce the possibility of adverse events occurring (or follow-on secondary events), to put in place protection and damage limitation measures that would reduce the consequences, to examine the efficacy of response mechanisms, and generally to improve the way that emergencies and disasters were managed.

By obliging local authorities and other asset owners to accept a share of the responsibility for restoring damaged infrastructure, central government's intentions were to transfer some of the risk, to limit its potential financial exposure, and to shift the focus to loss prevention and better overall risk management. As the "owners" of the assets, local authorities are best placed to identify local hazards and to implement strategies for ameliorating the consequences of any disasters. The outcome in the long run should be better protection of public assets, a safer environment for employees and society generally, less frequent interruption of essential community services, and a reduction in the financial impact of losses.

It has taken some years for local authorities to fully appreciate the intentions behind the changes. The initial reaction had been to focus on financial options for dealing with consequences such as infrastructural damage; and in particular to simply buy insurance. With time, however, some local authorities have started to acknowledge the wider benefits of pro-active risk strategies to eliminate or reduce potential losses. This is an encouraging trend. But it has also revealed the complexity of, and paucity of knowledge about, risk assessment involving disaster potential in New Zealand.

The Review of Emergency Services conducted last year, and more recent reviews on disaster planning, have highlighted the problem of uneven practices throughout New Zealand. Some local authorities are well advanced in their planning, others much less so. Whatever decisions Government might make about restructuring its arrangements for dealing with emergencies and disasters, it is clear that risk management will play a central role in the work of any new national organisation created to deal with emergencies. Not only will it be a source of practical advice on risk management for local authorities and others, but it will be in a strong position to advise Ministers on the best allocation of central government funding and resources across different risk categories.

An Emergency Science

As a formal intellectual discipline, risk management is still evolving and has some way to go to address very complicated systems. Explicit techniques have been around for many years in some fields such as engineering where deterministic outcomes are possible, i.e. where the behaviour of the system may be modelled according to some physical or chemical laws. The codes of practice developed for these relatively simple risk situations have led to many improvements in society e.g. buildings that stay standing after earthquakes, affordable cars etc. At a different level of complexity, the business world has developed its own practices that draw on risk methods for financial management. And there are interesting examples in the biological and health fields. But it was not until the 1960s when military and space requirements became increasingly demanding that risk analysis was formalised into a practical discipline to deal with complicated situations. At that point, attention shifted from failure analysis of individual components, to integrated assessments of the reliability of whole complex systems (e.g. satellites, computer controlled systems etc.). Modelling techniques became formalised; methods were developed to identify and improve the weakest links, and risk management gained credibility in many advanced industries.

RISK ANALYSIS AND EARTHQUAKES
Photo by Ross Land
Even in situations involving large uncertainties (e.g. earthquakes), or where absolute levels are impossible to define, the processes used in risk analysis can help to expose the strengths and weaknesses of different mitigation strategies and response mechanisms. In the 1987 Bay of Plenty earthquake the Edgecumbe Fault tore a scar across the Rangitaiki Plains.

In recent years, risk techniques have evolved still further to encompass human interaction with engineering systems, i.e. to combine predictable, quantifiable, technical risks with the uncertain reactions of human operators or natural systems. The safety of large facilities such as nuclear power reactors, industrial plants, and transportation networks can now be assessed in ways that allow for human reactions and failings, and that permit realistic estimation of the societal impact.

The critical factors requiring analysis in such situations warning times, response mechanisms, evacuation plans, etc. are all familiar ideas in the management of emergencies and disasters. They are readily transferable. The models now being developed to understand and assess the risks in such situations are far from perfect. But they are contributing to our understanding of the issues. The discipline of risk analysis is now at a point where its techniques can contribute significantly to the understanding of risks associated with managing emergencies and natural disasters and, more significantly, to reducing their potential impact.

Even in situations involving large uncertainties (e.g. earthquakes), or where absolute levels are impossible to define, the processes used in risk analysis can help to expose the strengths and weaknesses of different mitigation strategies and response mechanisms. They can point to ways in which overall risks to life and property can be reduced. And they can inform the choices that have to be made in allocating resources and effort for emergency management.

Risk Assessment

In New Zealand, those responsible for dealing with emergency and disaster situations have been slow to adopt risk control techniques. This is partly explained by the public scepticism that has developed over recent years in response to "expert" assurances about risks over which individuals have no control, or about which they hold different values (e.g. nuclear safety, mad cow disease ...). But it is also because the concept of risk can be difficult to grasp, dealing as it does with chance and uncertainty somewhere in the indeterminate future. At first sight, risk analysis seems to lack the rigour of some other disciplines and even as a process of applied science it appears to have methodological shortcomings.

Notwithstanding these perceptions, risk analysis can be a powerful aid in decision-making involving public safety or in dealing with potential emergencies and disasters. It forms an overlay on the emergency/disaster management process (i.e. the four phases of Mitigation, Preparation, Response and Recovery) which can help evaluate the contribution of each phase to overall safety management. Risk methodologies are useful not only for well understood situations where good empirical evidence and statistics are available (bridge design, fire suppression, river control, etc.), but also for situations in which there may be inadequate direct experience (e.g. a large volcano, epidemics, or environmental issues such as stratospheric ozone depletion).

Its particular strength for analysing situations of uncertainty stems from the fact that it offers a structured, systematic and consistent approach that forces the analyst into understanding the total risk picture. Provided that hazards are identified with care and consistency, that causal models are analysed logically, and that data is subject to strict quality control, the results of risk analysis will make a practical contribution to public safety and loss prevention.

Risk assessment may be defined and undertaken in many ways. Terminology varies among different risk practitioners. This paper is most closely aligned with the definitions used in the Australian/New Zealand Standard Risk Management, AS/NZS 4360:1995:

Risk Analysis

A systematic use of available information to determine how often specified events may occur and the magnitude of their consequences.

Risk Assessment

The process used to determine risk management priorities by evaluating and comparing level of risk against predetermined standards, target risk levels or other criteria.

Risk Management

The systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, treating and monitoring risk.
The essential idea is that it involves a formal, quantitative evaluation of potential injury or loss over a specified period of time, or the prospect of future mal-performance of a safety or security system. In the case of emergencies or natural disasters, it is a measure of the occurrence and severity of losses from a particular hazard.

The quantitative element is important. While the process itself of analysing a risk situation (e.g. effects of hydro-dam failure) can be valuable for identifying interdependencies and exposing cause-and-effect relationships between parts of a problem, the benefits are much greater when the contributing factors are understood in real numerical terms. This may not be straightforward in dealing with complicated situations such as emergency management in a major city, or adverse environmental events where there may be many variables related in complex ways.

Approaches to Assessment

But even semi-quantitative approaches can contribute significantly to the understanding and controlling of risks by putting bounds on possible outcomes. Risk techniques do not eliminate uncertainty, but help put it in context. Provided there is some appreciation of the degree of uncertainty in each of the factors in a defined situation, risk assessment can make an important contribution to reducing potential adverse effects.

In practice, there are usually no direct linear techniques for assessing risk. Experts tend to "gravitate" towards a conclusion through cyclical processes that may involve several independent approaches. For example:

- With natural hazards such as flooding, there may well be considerable **local experience** on which to base extrapolation to more serious risks.
- In some situations **observed records** and **expert views** will be highly valuable.
- In other situations where events are rarer (e.g. tsunami) it may be instructive to draw on **experience and practices elsewhere.**
- For some hazards, especially of a technological nature such as an accident at a chemical plant, it may be possible to consider the **physical limits** or **credible bounds** of the consequences to gain a feel for the worst case possible.
- In managed situations, such as complex hydroelectric schemes where a local authority's responsibilities may overlap with those of the facility manager, it may be best for the regional council to check that there is a **quality assurance system** in place.

- With unfamiliar hazards, the best solution may be to bring in **outside specialists** (under consultative arrangements that ensure the knowledge remains in-house) or to compare with similar sites elsewhere.
- In some unique situations, where there is no experience (global warming as a problem for small island states) it may be best to concentrate on **monitoring** programmes to establish good baselines for on-going trend analysis.

In general, using a variety of approaches will yield a more robust assessment and help avoid problems of systemic bias. It will also increase the likelihood of exposing rogue conditions or inter-relationships. For effective risk management, these different techniques should be utilised in ways that lead to a quantitative outcome where possible. The better the quantitative base, the better will be decision making, resource allocation, mitigation success and, ultimately, public safety or loss prevention.

Measuring Risk

Quantitative risk assessment combines three key ideas:

- the **chance** of something going wrong;
- the **consequences** if it does; and
- the **context** within which the situation is set.

For any given set of circumstances, the level of "Risk" may be calculated as the product of the "Probability" of an event or adverse outcome (chance/likelihood/frequency, expressed as occurrences per unit time) and a measure of the "Consequences" of the event (damage/detriment/severity, expressed numerically as a specific value measure such as lives lost or financial damage per event). In symbolic terms, we can write the equation **R = P x C**.

It has to be stressed that this simple product is not sufficient in itself to fully describe the real risk, but for a given situation in which the terms may be specified with reasonable accuracy, it provides an adequate basis for comparing risks or making resource decisions.

In this way it has become the basis for many risk assessment strategies, i.e. by providing a consistent basis for estimation it can permit different control mechanisms to be evaluated. In the typical situations faced by local authorities, for example, it would find application at two levels: within a specific risk setting it might be used to determine which of a number of mitigation options offered most protection; and within the entire set of risks to infrastructure faced by a local authority it might be used to decide where resources should be directed to achieve the lowest total risk for a given investment. At the national level, it could be used as a basis for

Government to decide where taxpayer funds might be best utilised to ensure public safety across a broad spectrum of emergency and disaster management situations.

Tolerable Risk

Decisions on the appropriate level of investment for dealing with natural and technological hazards depend critically on judgements about the acceptability of risk. Strictly speaking, no level of risk is "acceptable" but, as a point of principle, risk can be considered tolerable when there are commensurate benefits. Safety does not require all risk to eliminated: rather, that there be an appropriate balance among costs, risks and benefits.

ROAD ACCIDENT
Photo by The Evening Post
Road accidents in New Zealand claim about 600 lives each year. To what extent does the public tolerate this level of risk?

As in any analysis of this type, there will inevitably have to be value judgements made of one kind or another: what level of risk will individuals or society tolerate?

What proportion of ratepayers' funds should be invested in mitigation? What criteria should be applied?

At this stage there are no absolute standards available on acceptable risk, and there is strong opposition in some quarters to the idea of such standards being developed or regulated. (The Australian/New Zealand Standard Risk Management, AS/NZS 4360:1995, deals with processes for controlling risks but does not specify acceptable standards of risk.)

Public tolerance of risks commonly experienced in everyday life provides us with some indication of what is bearable. In practice, people usually have no hesitation in engaging in uncontrolled activities with very low probabilities, say 1 in a million years; they may engage in activities of low probability (say 1 in 10,000 or 1 in 100,000 per year) provided there are mitigating measures to limit the consequences; and they tend to avoid activities that might result in serious accidents if they occur with high probabilities say 1 in a 100 or 1 in a 1000 per year. (For comparison, New Zealanders have a chance of death in a road accident of about 1 in 6,000 per year.)

In just the way that individuals tend to set themselves personal thresholds of tolerable risk, so too communities have informal but real perceptions of **societal** risk thresholds. Travellers the world over continue to fly in jet planes notwithstanding the fact that, occasionally, accidents occur that kill 200 300 people at a time. Society would probably not accept say, one jumbo jet crash per week, but seems to tolerate one per year.

Clearly, when dealing with natural disasters in particular, it is not practicable to seek to achieve zero risk; the investment to make life totally safe would be beyond any government. This is more feasible when dealing with technological hazards but, even here, economics, risk acceptability, and the need for the technology have to be balanced carefully. Risk management experts recommend that, whenever feasible, those responsible try to eliminate high severity risks that might occur in a typical lifetime.

For any specific risk, they recommend trying to reduce dangers to just below a level commensurate with reasonable cost - the "As Low as Reasonably Practicable" (ALARP) principle. (Too conservative an approach to safety can easily end up costing more than the benefits.) A great deal of work has been done to try to devise standards of tolerability, but as yet they have not received universal acceptance. Desirably risks associated with all hazards, natural and technological, should be reduced to the point where they are low compared with levels that are widely accepted by the community without concern.

Management Strategies

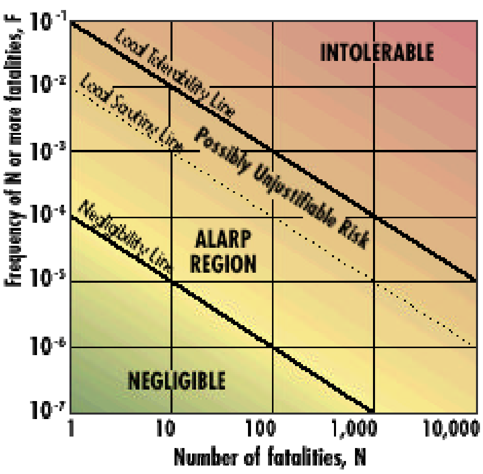

FIGURE 1: Indicative Frequency-Fatalities Curve
Figure 1 brings together several different concepts to do with the tolerability of risk. Derived from risk guidelines developed in the United Kingdom, it depicts risk thresholds in terms of local acceptability of deaths from industrial and other accidents. Plotted as exceedance or disasters involving a given number (N) of fatalities. The 'Local Tolerability Line" defines a region which is characterised by both high frequencies and severe consequences - the "Intolerable" region. The region between this line and the "Local Scrutiny Line" is a region of possibly unjustifiable risk. Between this latter line and the "Negligibility Line' is a region which is judged to be tolerable but for which all reasonably practicable steps should be taken to reduce the hazard further. This is the ALARP region (As Low As Reasonably Practicable). All combinations of frequency

The risk equation (R = P x C) points us to the two basic strategies for managing risk: we can try to lower the likelihood of an event happening; or we can try to reduce the consequences by putting in place suitable provisions for ameliorating the worst effects. In practice we should do both.

With natural hazards it is often difficult to do anything about modifying the likelihood of the primary event occurring, but we should be aware of possible problems from closely coupled systems and should aim to reduce the chances of further adverse events being triggered (i.e. secondary events such as flooding leading to dam collapse). By contrast, the likelihood of technological accidents can be modified in many ways: by good safety engineering, redundancy in design, self-regulation, fail-safe mechanisms, defence-in-depth, and proper training, operations and maintenance, for example.

In both situations we should also put in place protective or damage limitation measures, and other provisions (preparation and response and number of fatalities which fall below the 'Negligibility Line" are considered to be negligible.

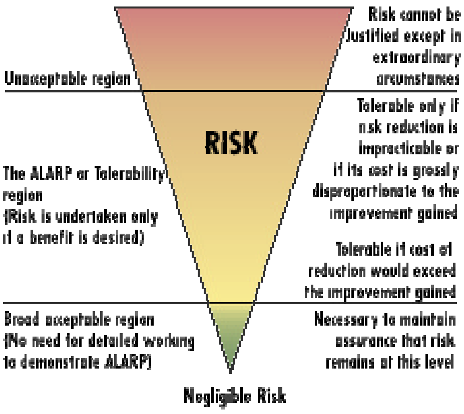

FIGURE 2 Above a certain level, a risk is regarded as intolerable and cannot be justified in any ordinary circumstances. Below such levels, an activity is allowed to take place provided that the associated risks have been made as low as reasonably practicable (ALARP). In pursuing ALARP, account can be taken of cost. It is, in principle, possible to apply formal cost-benefit techniques to assist in making judgements of this kind. Source: The Tolerability of Risk from Nuclear Power Stations, Health and Safety Executive, London, 1992.

etc.), to reduce the unpleasant effects should the event happen. The difficulty, of course, is in deciding on the balance of effort that should be applied to prevention (or reduction of likelihood) versus mitigation (e.g. containment, diversion, protection) or to any other aspect of damage limitation in the response and recovery phases. Low probability high consequence events present the greatest difficulty. Some highly unlikely circumstances such as meteorite impact are most efficaciously dealt with simply by repairing the damage the "do nothing" option. Others may be best dealt with by avoidance strategies, such as establishing an exclusion zone around a volcano.

This is where the techniques of risk assessment can illuminate the picture and point to the most effective allocation of resources to deal with the hazard. It will be necessary to weigh up the contribution of every item of "hardware" or "software" that has a bearing on the problem.

Hardware includes all construction, earth works, physical equipment, plant, detectors, alarms, containment systems and so forth, whereas software covers organisational structure, procedures, methods, skills, knowledge, documentation, training, inspections, attitudes, design codes, etc.

In developing strategies for managing both technological and natural hazards, it is important to consider the whole safety picture. The overall system risk is the summation of all the individual risks related to the initiating event, to the way that the damage unfolds, to the response, and to the recovery processes. Analysing the complete risk picture is never a trivial task, involving as it can independent risks occurring at different times, that may be controlled by different people and agencies.

Implementation Issues

In practice the local authority risk manager has the difficult task of controlling the risks from all public hazards in ways that not only maintain community safety, but minimise physical damage, and reduce social and economic disruption. More than most, that person must understand the big picture and avoid excessive reliance on any one sector such as the monitoring of developments, response, or insurance. Their task is to devise a management strategy that ensures every facet of the risk management process is understood, is operating well, and is in appropriate balance. They needs to anticipate potential weak points since failure at a single point in the logic or practice of a safety process may jeopardise the success of the whole.

For example, where a known hazard exists (such as the possibility of a river control system failing catastrophically) the risk manager has to understand the importance of each and every factor in the risk equation, and the relative contribution each makes to saving lives and minimising damage. The following are some of the more significant considerations:

- Know what can go seriously wrong, when, and with what forewarning.
- Examine ways to reduce the chance of it happening.
- Put in place measures to contain the worst effects, divert them away from communities, or otherwise reduce the severity of the impact.
- Anticipate what might go wrong with the mitigation measures and any new risks they may introduce.
- Test whether the warning time is sufficient to evacuate people (and decide whether the warning system and communications can be relied upon to work properly).
- Be familiar with all aspects of the response mechanisms (who, how, when, how reliable, contact numbers, availability, alternates etc.).
- Consider specific public education or training that might improve the community's reaction to the warning.
- Anticipate what might go wrong in the response phase, and what new risks it might introduce.
- Decide how the injured will be dealt with to minimise further loss of life.
- Develop plans for recovery (people, materials, finance, insurance etc.).
- Look for opportunities to test and evaluate the entire system (especially with small events), and make adjustments.

The importance of having a clear picture of the nature and scale of a potential disaster and of every step along the way through response and recovery was brought out clearly at the time of Mt Ruapehu's eruption last year. That exercise, part of which appears as a case study elsewhere in this issue of Tephra, demonstrated the importance of the risk management process not only being analyzed in the widest possible context, but being evaluated as a sequence of explicit steps (monitoring, data analysis, hazard assessment, warning, communication to local authorities, dissemination of warning in the community, reaction, evacuation, emergency services, medical services, recovery). Success depended on each and every step functioning correctly and at the right moment. Failure of any one or a delay in communication could negate effort elsewhere and jeopardise the entire process.

Resource Allocation

An important corollary is that there is no point in having any one step functioning excessively well. Each step should yield an outcome of equivalent quality in terms of its contribution to the overall safety process. Anything else represents a less than optimum use of resources.

That is not to suggest that effort and resources should be applied uniformly to each step, but rather that each should receive support commensurate with its importance or potential for improving the outcome. Moreover, in complex situations involving many variables and uncertainties the precision with which the overall risk can be determined will be dominated by the most uncertain or crudely known factor. That should set the standard for the entire system. For example, if evacuation of a danger zone will take two hours, warning systems must be able to give at least that amount of advance notice of a rising danger anything less will not contribute to safety. (The Ruapehu case study makes reference to the important "Principle of Consistent Crudeness" for the optimisation of complex system models.)

Quality assurance processes can make a significant contribution by ensuring that all parts of a system including technical issues, organisational structures, management, personnel training and so forth are operating in optimum balance.

Moreover, it is essential for the efficient allocation of resources that authorities responsible for the control of disparate risks examine each with consistent methods using similar standards. The most sensible goal for any local or central government is to understand and mitigate its most serious risks to public safety and infrastructural damage in ways that achieve an approximate balance in levels across all constituent risks.

Practical Application

PALMERSTON NORTH 1988 *Photo by The Evening Post*
There are unquestionable benefits in knowing as much as possible about local hazards and in improving the understanding of risk and its control.

It is not the intention of this paper to detail all of the steps used in developing risk strategies. That will depend on the risk being analysed.

The process, however, typically involves three broad phases:

- assessing the risks quantitatively;
- applying reasonable and effective safety and loss control measures; and
- evaluating the effects of the overall risk management programme.

These are set out in greater detail in the chart alongside, which represents the processes that a local authority might go through in doing a comprehensive risk study. For the sake of clarity, the sequence has been broken into five broad steps: Analysis, Estimation, Evaluation, Control and Verification. Other approaches are possible depending on the nature of the risk, but the process of quantitative risk analysis would normally involve most of the steps detailed.

In an ideal world, a local authority or other risk manager would undertake a series of risk analyses covering all the risks falling within their jurisdiction in order to rank them in importance and to apportion funding for mitigation. In practice, experience and pragmatism would mean that only the most significant risks would be subject to comprehensive analysis of this type. The degree of analytical effort applied would tend to reflect the scale of risk, potential benefit, and familiarity with the hazard (e.g. expert judgement and experience might be given greater weight than other techniques in determining risks). But, regardless of the degree of formal evaluation, there are unquestionable benefits in knowing as much as possible about local hazards and in improving the understanding of risk and its control.

Experience overseas has shown that risk management is most effective when those responsible for the risk fully accept ownership of the assessment and control processes. In particular:

- Local authorities need to fully understand their local risks themselves. The practice of employing external contractors does not encourage those with the ultimate responsibility to gain the qualitative insights necessary for informed management. And, in-house knowledge is essential to understand the implications for safety under unusual circumstances or when elements of the hazard change with time.
- Assessment should be specific to a category of risk (e.g. flooding of a defined section of a lake or river) or to a particular facility or hazard (e.g. hydro-dam or volcano). Results from similar situations elsewhere may be relevant, but considerable care is needed in adapting from other experiences.
- Risk management can not be done purely on the basis of codes of practice or regulations. Risk managers need to take responsibility for the total risk situation, not merely demonstrate compliance with general safety regulations.

Conclusion

Disasters can be difficult problems to address. They are inevitably complex and characterised by high levels of uncertainty. Typically they involve low probabilities and high consequences, making them difficult to analyse. The most serious events are (fortunately) the least likely to happen, but this also means there is often a lack of reliable data. Data that does exist may be held anecdotally or in a variety of forms by different agencies. And, not least, because of their potential to affect people adversely, they can end up being the subject of conflict or controversy.

The analytical techniques now becoming available for interpreting situations of this type have much to offer those responsible for public safety and loss prevention. Risk management strategies of themselves cannot guarantee better performance because of both the role that chance and uncertainty play, and the vagaries associated with human intervention. But the methodologies used for assessing risk can contribute to understanding where the most serious components lie. They can point to the more promising control options, assist policy development, and inform the allocation of resources.

Risk analysis is therefore going to be used increasingly in the management of emergencies and natural disasters in New Zealand. The message from Government is clear. Those responsible for public safety and for managing infrastructural assets in New Zealand are obliged to assume full responsibility for managing the risks, i.e. to identify the hazards, to assess the risks, and to take whatever precautions are required. Support from central government is conditional upon proper risk management having been demonstrated. These are not matters that can be regulated in Wellington. It is up to the local authorities or asset owners to take responsibility for balancing the costs, risks and benefits in the best interests of the communities they serve.

Risk Management Strategy for Natural and Technological Hazards

ANALYSE

- Understand the context of the hazard, existing controls, and safety objectives.
- Treat all aspects of the hazard and its management as an integrated system.
- Identify sources of all hazards, vulnerabilities, threats and potential losses associated with the event, activity or system.
- Clarify potential problems, trigger mechanisms, and conditions of exposure.
- Develop models, and establish relationships between cause and effect.
- Analyse consequences of all possible outcomes, especially safety aspects.
- Consider threats to life, property and environment separately.
- Consider records, empirical evidence, experience elsewhere, and expert opinion.

ESTIMATE

- Quantify all factors objectively, and determine uncertainty.
- Carry out sensitivity analysis for the dynamic situation.

- Consider physical limits and worst credible bounds (e.g. using statistical inference and scientific postulation).
- Define character and magnitude (size or severity) of consequences.
- Estimate chance (likelihood or frequency) of event or condition.
- Calculate component risks and overall risk using Probabilistic Risk Assessment.

EVALUATE

- Determine significance of estimated risks (in absolute and comparative terms).
- Consider acceptability (in terms of both individual and societal tolerance).
- Study economic impact and funding options for response and recovery.
- Examine costs and benefits of control for most serious risks.
- Assess cost risk benefit balance.
- Decide to accept, reduce, or transfer risk.

CONTROL

- Minimise, Mitigate and Manage risks, i.e.: develop ameliorative measures that:
    - lessen likelihood of event and/or consequent system failure;
    - lower magnitude of consequences;
    - provide resources for response and recovery.
- Consider all possibilities for risk reduction:
    - design for safety, using prevention, protection, and damage limitation;
    - reduce uncertainty, monitor constantly, maintain and upgrade systems;
    - set standards and apply quality control at all steps;
    - develop defence-in-depth (layered response) to counteract small failures;

- reduce likelihood of human error or perversity
  (training and safety culture).

VERIFY

- Test effectiveness of risk reduction strategies.
- Obtain independent safety audit and inspection.
- Establish incident reporting methods that include responses etc.
- Establish feedback mechanisms to learn from experience, then re-prioritise.
- Develop compliance programmes covering management, training and procedures.
- Assess cumulative system risk across all stages (including any additional risk introduced by intervention, i.e. mitigation, preparation, response and recovery).
- Establish quality assurance mechanisms to have all parts optimally balanced.
  Continually monitor, review and improve systems.

Ruapehu erupts *Photo by Aurther Pengelly, September 1995*

Case Study:

Mt Ruapehu 1995

by Patrick Helm
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One of the first attempts within Government at formal risk analysis of a natural hazard came about last October as Cabinet was considering options for dealing with the elevated level of volcanic activity at Mt Ruapehu. Officials at that time came together in a series of meetings with geophysical and risk experts to examine the situation from a public safety perspective.

While it was not possible, given the nature of the problem and the lack of reliable data, to prepare a full quantitative risk assessment for Ruapehu, the analysis did help expose the relative significance of the individual risk elements. In particular, it highlighted the importance of analysing the problem not simply in terms of the likelihood of eruption, but in terms of the safety of the whole situation, i.e. before, during and after an event. It also underscored the importance of maintaining a balance of effort and funding across all aspects of the potential disaster so that there were equivalent contributions to safety in each phase.

The text which follows was prepared originally after the peak of activity, as part of a paper to address specific questions set by Cabinet relating to the value of on-going monitoring. The thrust of the paper was not so much to determine what level of monitoring was appropriate for the activity under consideration, (that ultimately involved difficult value judgements and was treated separately), but to ascertain the need for and role of monitoring in contributing to public safety. As a case study in dealing with natural hazards it usefully brought out the need to understand the complete integrated risk picture in allocating resources. Operationally, it also underscored the need to ensure that each and every stage in the safety chain was matched appropriately to its neighbours, and that on the day they would all function as intended. Any weak link had the potential to jeopardise the total safety process.

Risk Analysis

Ruapehu's behaviour, like that of all volcanoes, is largely unpredictable. But there are techniques that permit risks to public safety to be evaluated with some degree of confidence. Past patterns of activity, trend analysis, and expert judgement can help narrow the range of possibilities at any one time. So too, being prepared with sensible response mechanisms can help mitigate the worst of effects.

In attempting to analyse Ruapehu's risks, therefore, officials focused on the question of whether Crown intervention through monitoring the volcano and the establishment of sensible precautionary response mechanisms in the nearby areas could be expected to contribute significantly to improving public safety.

As in all matters of public safety, a balance is required between the benefits to the people or society concerned, and the costs of achieving them. The issue is not one of eliminating all risks; that would require evacuation of all towns, including Taumarunui, for many months possibly years. Rather, it is to reduce the overall risks to be "as low as reasonably practicable" (ALARP). The ALARP principle is widely accepted in Western societies. The optimum level of safety is when the risks have been reduced to the point where the marginal cost (of extra precautions) equals the marginal benefit (in safety).

In the case of natural phenomena, such as volcanoes, where events are few and far between, but the consequences potentially large, pure quantitative approaches (such as that applied to engineering risk) are not possible. There are, however, other techniques involving semi-quantitative analysis that can help throw light on the most likely risks their nature, possible scale (size), credible limits, likely directions, and probable impact.

In quantitative analysis, risk is frequently thought of and evaluated in terms of the probability of an event and the consequences. (Risk = Probability x Consequences). For a volcano, nothing can be done about the first term, i.e. no intervention will change the likelihood, frequency or timing of any eruptive event. But, the magnitude of the consequences (safety impact, and scale and types of damage) can be influenced if suitable precautions are in place, adequate warning is given, and response mechanisms function effectively.

Risk Evaluation

There is no single line of analysis that can provide answers on the risks for Ruapehu. Officials, therefore, have taken a variety of independent and complementary approaches in the belief that a concordance of all will help illuminate the issues, identify the critical factors, and point to the most effective forms of mitigation.

The analysis to date has included:

1. Examination of Ruapehu's behaviour in this event; recent other events; and historical patterns;
2. Consideration of volcanoes generally, including experiences and precautions elsewhere;
3. Consultation with experts in volcanology and various geophysical disciplines;
4. Consideration of credible worst effects, and natural limits;
5. Consideration of consequences if the credible worst should happen;
6. Checking of the warning and response systems in place; and
7. Consideration of mitigative measures.

Nature of the Risk

Ruapehu, September 1995 *Photo by the New Zealand Herald*
The Chateau is dwarfed by clouds of ash from Ruapehu's crater

Consultation by officials with scientific specialists from the Crown Research Institutes and universities revealed nine discrete forms of hazard relating to the primary event:

projectiles ("bombs")
lava flow
pyroclastic flow from the existing crater
pyroclastic flow due to build-up and collapse of lava dome
landslide/rock avalanche
toxic gas emission
lahar
ash fall
ash plume

These are considered in more detail in Table 1, where each element is weighed for its contribution to the overall risk.

The conclusion is that, at current levels and given the existing distribution of the local population, the societal risks are small. They are higher, obviously, for any individuals who deliberately breach the exclusion zone around the crater. There could be significant adverse economic affects (closure of ski fields, stock losses, machinery damage, etc.), but the impact on public safety would not be large.

Should the volcano revert to high levels of activity, the energy released could increase 10 100 times. The risk to public safety would increase in two ways: the magnitude of the various hazards would rise, and the warning time would decrease allowing less time for effective response. The combination of effects may jeopardise public safety. (In the last 1800 years, Ruapehu has had 18 eruptions of roughly the magnitude of the present event; none were markedly larger.)

Warning Issue

The value of monitoring, therefore, lies not so much in measuring the size of current phenomena but in observing trends up or down. Officials have concluded that, at current activity levels, monitoring need be only sufficient to reliably detect an upward trend. This can be achieved through daily checking of seismic records that are transmitted from seismographs on Ruapehu to the Institute of Geological & Nuclear Sciences (GNS) research centre in Wairakei. Currently, more specialised monitoring would contribute more to scientific ends than those of public safety. At present low levels, expert opinion is that there should be considerable warning of a major escalation days, possibly weeks. If the volcano activity moves to level 4 or higher, more intensive monitoring would be needed to achieve the requisite warning time. Paradoxically, the value of monitoring may diminish at very high activity levels where eruption may occur with little build-up, because warning times become insufficient to achieve a useful response in nearby communities.

The significance of monitoring in respect of public safety, therefore, lies primarily with the warning time that it provides; to a lesser extent it also gives information about the nature of the hazard. It is of value to public safety only in so far as it provides sufficient time (i.e. several hours) for local authorities and civil defence controlling agencies to take appropriate action, i.e. to evacuate threatened people or to put in place other mitigative measures. The costs of monitoring have to be decided in relation to the overall safety process: mitigation, preparation, response and recovery.

Response Issue

In dealing with potential natural hazards such as volcanoes, there are two broad approaches:

- to choose deliberate inaction, or some prudent evacuation/exclusion; or
- to prepare to react, and to put in place measures to avoid or ameliorate the worst effects.

The latter situation, which is what we have now, is characterised by the following steps and processes.

REACTIVE SITUATION	
• Monitor • Process/analyse/interpret/assess • Communicate warning • Preparations by Local Authorities etc.	fore-warning process
• Dissemination of warning • Reaction - mitigation - evacuation • Response Activities - emergency services - medical services • Recovery	response process

In considering responses to events on Ruapehu, there needs to be an effective balance maintained between **all** of the factors that contribute to the risk equation, i.e. the event itself, and the responses. The risk to public safety is a convolution of each and every one of those factors. The outcome (lives saved with minimum social and economic disruption) depends on every step functioning successfully; if any fail, the effort applied elsewhere is wasted.

In risk management there is a Principle of Consistent Crudeness, which in situations of this type says that the effort and funding applied to any one part of the process should be commensurate with all of the others in the sense of yielding an equivalent improvement in outcome. Conversely, excessive attention to any one part will represent a poor use of resources if there are weaknesses elsewhere.

Conclusion

As a result of the events of the last several months, local authorities and others likely to be affected by Ruapehu have put in place a range of precautionary measures. These cannot guarantee that there will be no loss of life if there are major developments on Ruapehu. But the risks are low. Those responsible believe that the measures in place are appropriate for the relatively quiescent situation we have now, and that they could be upgraded quickly to deal with a higher alert level.

That being the case, there is little value in high intensity monitoring. Officials are not convinced that higher levels can be justified in view of the imbalance that would be created with the many other elements that make up the overall risk equation. That is, additional resources for monitoring would not necessarily save more lives or reduce damage to property. In the current situation the need is for continued periodic monitoring at a level sufficient to ensure that any major trends towards increasing activity are reliably detected. Additional monitoring would be required only if there were to be a significant reversal in the present downward trend.

Acknowledgements

The meetings to examine the risk situation presented by Mt Ruapehu's activities were convened and chaired by the Ministry of Civil Defence, Wellington. The risk analysis process was facilitated by Professor David Elms of the Department of Civil Engineering at Canterbury University. Among his other significant contributions, (not least being his earlier development of the so-called Principle of Consistent Crudeness for the optimal development of complex system models), he compiled the risk assessment table reproduced at Table 1. The input to that table and the discussions generally from the geophysical and volcanological specialists and other scientists who participated in the meetings is acknowledged, as is the contribution from the Director and staff of the Ministry of Civil Defence.

TABLE 1

TABLE 1	Assessment of risk of harm to people arising from Ruapehu at alert level 3							
TYPE OF EVENT	**AREA OF IMPACT**	**PROBABILITY OF EVENT**	**PEOPLE AFFECTED**	**BASIC RISK OF HARM TO PEOPLE**	**MITIGATION STRATEGIES**	**CAN MONITORING OF ACTIVITY HELP?**	**MONITORING HELP**	**SIGNIFICANCE OF RISK REDUCTION DUE TO MONITORING**
Localised (projectiles, lava flow)	Less than 1.5km from crater	Significant	Nil	Negligible	Evacuation	No	Nil	Negligible
Localised (projectiles, lava flow)	Greater than 1.5km from crater	Negligible	Nil	Negligible	Evacuation	No	Nil	Negligible
Lava dome collapse	Some kilometres probably to east	Low	On mountain or Desert Road (motor vehicles)	Low	Evacuation	Yes	Visual observation of crater	Low
Landslide/ rock avalanche	Some kilometres	Low	On mountain or Desert Road (motor vehicles)	Low	Evacuation	Yes	Visual observation of crater	Low
Toxic gas	Some kilometres	Negligible	Few	Negligible	Evacuation / warning	No	Nil	Negligible
Lahar - small	Defined trails	High	On mountain only	Negligible	Warning - anticipatory	Yes	1. Build up of seismic activity (hours) 2. Visual observation of how much material and	Negligible

							where it is 3. Visual observation of crater whether lake exists	
Lahar - medium	Defined trails	Medium	On mountain and some roads	Low	Warning - within defined areas	Yes	1. Build up of seismic activity (hours) 2. Visual observation of how much material and where it is 3. Visual observation of crater whether lake exists	1. Low 2. Low 3. Low
Lahar - large	Defined trails	Negligible	Ohakune, Turangi, Waiouru	Negligible	Warning, evacuation and roading/railway closure	Yes	1. Build up of seismic activity (hours) 2. Visual observation of how much material and where it is 3. Visual observation of crater whether lake exists (2&3 have immediate seismic observation)	Negligible
Ash fall	Broad area dependent on winds	High	Health if significant fall. Fatality - negligible. Has significant economic effects	Medium	Warning - in hours	Yes	1. Build up of activity giving warning then: 2. Check seismicity frequently	1. Medium 2. Medium
Ash plume	Broad area of flight paths	High	Aircraft passengers and personnel	High	Warning - to aircraft to avoid plume	Yes	1. Seismicity reading (hours) 2. Visual observation 3. Satellite (in fine weather only)	1. Significant 2. Provides specificity 3. Corroborative
Escalation beyond Alert Level 4 in scale of eruption cycle	Broad area	Low	Very large numbers	Medium	Civil Defence alert, warning and advice. Evacuation	Yes	1. Seismicity (days/weeks) 2. Ground deformations 3. COSPEC (S02 gas) analysis (1, 2 & 3 identifying a trend)	1. Significant 2. Significant 3. Significant