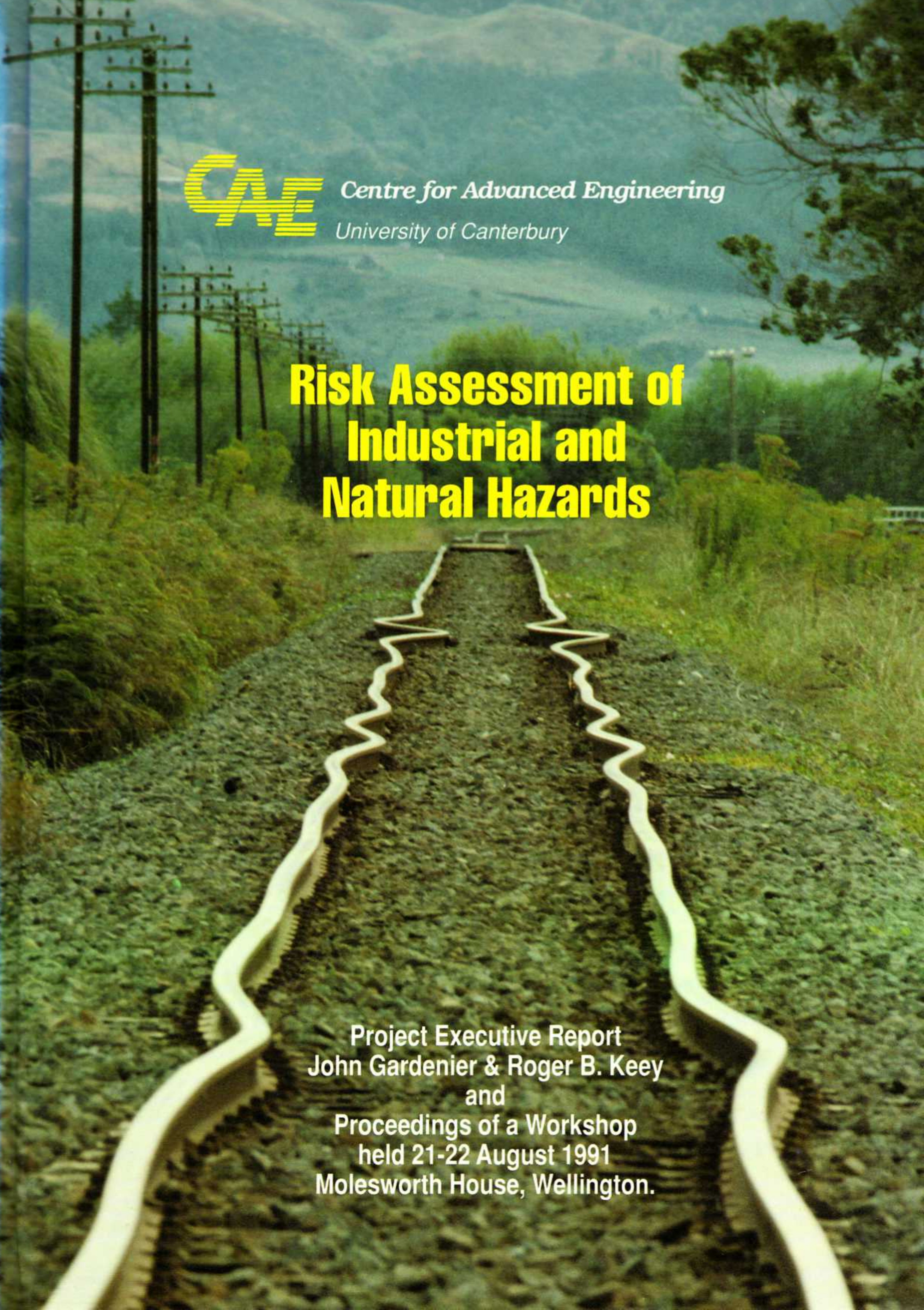

Centre for Advanced Engineering
University of Canterbury

Risk Assessment of Industrial and Natural Hazards

Project Executive Report
John Gardenier & Roger B. Keey
and
Proceedings of a Workshop
held 21-22 August 1991
Molesworth House, Wellington.

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ISBN 0-9598002-3-9

Cover Photograph

Reproduced with permission from DSIR Geology and Geophysics. The Edgecumbe earthquake of March 1987 created many distortions in both the natural and man-made environment, as the curves in the railway line clearly show.

Printing

The Printery, University of Canterbury

Centre for Advanced Engineering

Establishment

The Centre for Advanced Engineering was founded in May 1987 to mark the centenary of the School of Engineering at the University of Canterbury. It was established by means of an appeal fund launched in conjunction with the centennial celebrations. To date approximately $2.3 million has been raised, contributed by 150 corporate donors and 450 individual donors. The earnings from this capital sum are used to run the Centre and fund its activities.

Objective

The objective of the Centre is to enhance engineering knowledge within New Zealand in identified areas judged to be of national importance and to engage in technology transfer of the latest research information available from overseas. The Centre is not concerned with basic engineering research, but with the application of research findings to engineering problems.

The objective is achieved for each major project undertaken by bringing together a selected group of practising and research engineers and experts in the particular field from both New Zealand and overseas to:

- consolidate existing knowledge
- study advanced techniques
- develop approaches to particular problems in engineering and technology
- promote excellence in engineering
- disseminate findings through documentation and public seminars

A unique forum for co-operation among industry, the engineering profession and university research engineers is thus provided.

Function

The Centre is controlled by a Board of Directors comprising representatives from industry, the engineering profession and the University of Canterbury. Chairman of the Board is Mr Peter Menzies of Auckland.

The Board selects the title for each project undertaken by the Centre and approves the level of funding. A Steering Committee is then appointed, initially to carry out detailed planning for the project and then to provide overall direction. The Steering Committee appoints Task Group Leaders and a Project Manager.

Detailed work on the project is carried out on a voluntary basis by the members appointed to each Task Group. The Centre arranges to bring to New Zealand, at the appropriate time, several Visiting Fellows to work with members of the Task Groups, bringing into the project the latest available information from overseas.

The Centre also undertakes smaller projects, such as the one described in this report, on engineering subjects of current concern, and arranges lectures and seminars on appropriate topics as the occasion arises.

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Acknowledgements

The project has received widespread support from the individuals who contributed to it on a voluntary basis and from the organisations they represent, as detailed in the individual papers. Their efforts are much appreciated.

The major contribution made by the Project Leaders, Mr John Gardenier (Gardenier Consulting) and Professor Roger Keey (University of Canterbury), is gratefully acknowledged.

The Centre for Advanced Engineering is also very grateful to the following sponsors for their financial support for this project:

- **Department of Health**
- **Ministry for the Environment**
- **Institution of Professional Engineers New Zealand**

Foreword

When the Centre for Advanced Engineering (CAE) was being established in 1987, Professor Roger Keey, at the invitation of the Dean of Engineering, proposed a major project on the subject of "The Assessment of Major Industrial Hazards". This was considered along with other project proposals when the Board of Directors for the Centre first met in July 1988.

This proposal was not selected as the first CAE Major Project, but late in 1988 two Standing Committees of the Institution of Professional Engineers New Zealand (IPENZ) both expressed an interest in the area of risk assessment.

- The IPENZ Standing Committee on Engineering and Environment noted New Zealand's exposure to natural hazards, and the need to be up-to-date with the state-of-the-art in such areas as hazard analysis and risk assessment, dealing with hazardous materials, and earthquake engineering and seismology.
- The IPENZ Standing Committee on Engineering Safety noted that there had been considerable interest recently in the risk and frequency of natural occurrences. It was suggested that CAE might consider a study of what is known about the risks and frequency of natural occurrences as a project.

Also, in February 1989 it was noted that the Ministry for the Environment had included Risk Management in their *Environmental Research Agenda 1989-1992*, and that the proposal being developed for the Resource Management Act referred to the link between industrial and natural hazards. A successful application was made to the Ministry for the Environment for funding under this Agenda.

Subsequently, the Department of Health indicated they would also provide financial support for a project studying industrial and natural hazards.

A proposal was then developed by Mr John Gardenier and Professor Roger Keey to prepare an "Introductory Report on Risk Assessment of Industrial and Natural Hazards". The proposal noted that methodologies underlying estimation of risks and associated public perceptions of hazards often differ widely, such as those relating to major industrial accidents, traffic accidents, fire, earthquake, volcanic eruptions, river and coastal floods, dam failure or general health hazards.

Approval to proceed with the Introductory Study was given by the CAE Board of Directors in September 1990, with CAE as the principal sponsor and financial support also being given by the Department of Health, Ministry for the Environment and IPENZ.

Subsequently, the project was also endorsed for registration as a project under the International Decade for Natural Disaster Reduction being co-ordinated within New Zealand by the Ministry of Civil Defence.

As part of their funding for the project, the Department of Health sponsored two seminars on "Risk Management for Health Protection Officers" held in Wellington on 11-12 October 1990 and 7-8 February 1991. These Seminars were very useful as a forerunner to the main project.

Mr Gardenier and Professor Keey, as Project Leaders, then planned and co-ordinated the work carried out in preparation for the CAE Workshop held in Wellington on 21-22 August 1991, at which 16 position papers were presented , together with briefing papers prepared by each of the Project Leaders.

Following the Workshop, the papers were edited. A brief summary of Workshop discussions was also written, together with a Project Executive Report prepared by the Project Leaders. These documents all comprise this report, entitled "Risk Assessment of Industrial and Natural Hazards".

As noted in the Workshop Recommendations (Appendix 4), the participants found that considerable further work needed to be done and it is hoped that publication of this Report will lead to ongoing dialogue and studies on the subject of risk evaluation within New Zealand.

J P BLAKELEY
EXECUTIVE DIRECTOR
CENTRE FOR ADVANCED ENGINEERING
UNIVERSITY OF CANTERBURY

CONTENTS

RISK ASSESSMENT OF NATURAL AND INDUSTRIAL HAZARDS

PROJECT EXECUTIVE REPORT

John Gardenier and Roger B Keey

1. Introduction

This project is concerned with an introductory study of industrial and natural hazards. Methodologies underlying estimation of the risk of unwanted events differ, as do people's perceptions of such hazards. The purpose of the project is to draw together views on risk assessment over a range of applications, with the aim of determining the best use of quantitative methods for evaluating typical hazards found in New Zealand. It is hoped that the study will ease consent procedures by providing a basis for rational planning and development, and will lay the foundation for a hazards database for New Zealand.

Project Leaders were John Gardenier of Gardenier Consulting, Wellington, and Roger B Keey, Professor of Chemical Engineering at the University of Canterbury, Christchurch.

It is noted with satisfaction that the work has been endorsed for registration as a project under the International Decade for Natural Disaster Reduction.

2. Project Structure

Originally it was thought the project would be an adjunct to the one sponsored by the Warren Centre for Advanced Engineering at the University of Sydney in 1986, which was concerned with major hazard identification and risk control for the chemical and related industries. As noted in a separate review included in the Appendices, some of the conclusions of that study have been overtaken by lessons learnt from more recent major incidents. These include the specific hazards of offshore installations, the need for 'life-cycle' safety management and the review of existing processes and plant in the light of new knowledge or technology. Moreover, the present project is concerned with the search for a unitary framework to describe and manage both industrial and natural hazards rather than a detailed examination of the hazards which may arise in a particular group of industries.

Introductory to the main project, two-day seminars for health protection officers were run by the Project Leaders in December 1990 and in February 1991 under the auspices of the Department of Health. These seminars were concerned with the application of quantitative measures in assessing public health issues and in risk management.

Currently, the diffuse recording of data and delayed appearance of some health effects mean that quantitative methods have limited direct application.

These problems reveal the need for more universal, but perhaps less sophisticated hazard assessment techniques than those presently used in the process industries to evaluate potential hazards of far-reaching effect.

The central feature of the project was a workshop to which selected practitioners in the fields of engineering, environmental and earth studies, health services, economics, insurance and planning disciplines were invited. Full proceedings of the workshop, held 21-22 August 1991 in Wellington, are also included separately. Participants were invited to prepare position papers in response to briefing papers written by the Project Leaders. These position papers, together with the briefing papers, are ranked alphabetically by author, preceded by guidelines for authors and general issues for discussion at the workshop itself. Thereafter follow comprehensive summaries of discussions of individual papers, of general issues, and of adopted recommendations respectively. Finally, a list of participants is given.

The Executive Project Report presented here is primarily a commentary on observations made at the workshop, and on its recommendations for further collaborative action.

A summary of this study was presented at a feature session of the Annual Conference of the Institution of Professional Engineers held in Christchurch in February 1992. Other presentations may follow.

3. Position Papers

Position papers presented at the workshop confirmed that risk assessment approaches by different disciplines often have little in common with each other. Some disciplines hardly follow a systematic approach, while others know what they want, but have no data (see Prebble paper page 107). Many have not yet been able to start quantifying risks in their field. Yet discussions at the workshop showed that participants felt that they could learn much from each other, but that a common language or method of exchanging risk information needed to be developed. The comments presented under the various headings below enlarge on significant points considered at the workshop.

3.1 Definitions of Risk and Hazard

Presentations at the workshop confirmed that the terms 'risk' and 'hazard' may be used differently by practitioners in various fields, and it is well known from international literature that this often gives rise to an element of confusion at meetings and conferences. A feature of the workshop was the easy consensus towards the need for a common terminology as the starting point for a unitary framework for hazard evaluation and risk management.

The workshop tentatively accepted the following definitions:

- ***Risk*** is the probability of a specific hazard, loss or detrimental outcome happening within a defined period of time.
- A ***hazard*** or ***danger*** is a threat which, should it happen, may have an adverse effect on the environment.
- The ***environment*** includes ecosystems and their constituent parts, including people and their communities, natural and physical resources and amenity values (adapted from the Resource Management Act 1991).

As noted in the workshop's recommendations, a Study Group was formed to prepare acceptable wording guidelines to cover all significant risks, irrespective of type. Members are Professor David Elms of the Department of Civil Engineering, University of Canterbury; Mrs Janet Gough of the Centre for Resource Management, Lincoln University; and Professor Roger Keey of the Department of Chemical and Process Engineering, University of Canterbury, as convener.

The Study Group would need to consider that the definition of risk, as presented above, may need further development to be useful for practical application by risk managers in the field. The definition, for instance, does not address the fact that risk has two components: probability, not only of occurrence, but also of potential consequence. Moreover, the definition does not distinguish between the different layers of risk involved in risk analysis. At the workshop it was noted that risk could usually be seen as the product of three probabilities, namely: the risk (p_1) of an incident occurring at a source some distance away, the risk (p_2) of the effect of that incident reaching a certain feature in a certain place, and the risk (p_3) that this would have a specific negative consequence for that feature. In casual conversation the various risks are easily confused with each other, however risks can only be compared within their own kind. For example, the chance of being killed in an industrial accident cannot be simply compared with the chance of an earthquake occurring at the same place. The proposed definition does not alleviate such practical problems.

3.2 Risk Calculations

The briefing and position papers have revealed some semiquantitative rapid-ranking techniques for assessing risk levels and hazard impacts. Essentially these methods formalise judgements within value scales and have been developed to assess various kinds of risks, including hazards to the environment and dangers from natural events such as seismotechtonic and volcanic activity. A Study Group was formed to evaluate the various methods and to determine if there was a preferred rapid-ranking technique that could be used over a wide range of applications. This Study Group consists of Mrs Jennifer Boshier of the Office of the Parliamentary Commissioner for the Environment; Professor David Elms of the Department of Civil Engineering, University of Canterbury; Mrs Janet Gough of the Centre for Resource Management, Lincoln University; and Professor Roger Keey of the Department of Chemical and Process Engineering, University of Canterbury, who is the convener.

This could prove to be an important initiative, given that major natural disasters may involve similar or larger economic loss in comparison with large accidents of technological origin. This similarity poses questions of parity of protection from various kinds of dangers and other issues in land-use planning. A common assessment tool would be essential in providing comparative risk information, which could have an important bearing on decision making. We therefore recommend that the Board underwrite this initiative by supporting the study expenses of the Study Group and arranging for the dissemination of the results.

The following points need to be considered:

The Study Group would have a strong incentive to link the preferred rapid-ranking risk assessment techniques with standard quantitative risk assessment (QRA). This would allow the same or comparable risk concepts to be used for any rapid-ranking system with the advantage that QRA results, when available, could be incorporated in the chosen rapid-ranking method. Such an approach would also be essential for exchanging risk information between disciplines and communicating with lay people.

While QRA methods often use mortality data to indicate risk levels, since such data are generally available and reliable, quantitative methods are not limited to a mortality scale. An early study of LPG related hazards for the Liquid Fuels Trust Board (LF 2019:1982) included damage calculations of land areas possibly affected. Further, alternative indices to mortality rates for evaluating the impact of hazards on persons are appearing in the literature [Trans I Chem E, vol 69 Part B, pp.85-89, 1991]. These approaches have advantages when detailed risk assessments are impractical or data scarce.

Formal QRA incorporates considerable uncertainties, and results may vary by at least one order of magnitude. Presumably, rapid-ranking methods incorporate greater uncertainties because their widespread use may lead to unwarranted conclusions. The Study Group would therefore need to check the results of these simpler methods against more rigourous analyses.

3.3 Risk Mapping

As a complementary step, the workshop also agreed to set up a Study Group to investigate the feasibility of drawing overlaid risk and hazard maps for both industrial and natural hazards, with the Taranaki region as a possible example. The practical importance of this initiative is that risk mapping provides a uniform means of communication, not only between disciplines, but also with the public when public apprehension needs to be addressed. Original fears that such maps would increase public apprehension have not been substantiated overseas in the long-term. Hazard maps have already been prepared for some central North Island areas of New Zealand, for specific consequences of volcanic activity, such as mudflows. The preparation of such hazard and risk maps would test the practical usefulness of rapid-ranking proposals.

We therefore recommend that the Board also underwrite the expenses of this Study Group in a manner similar to the proposed support for the work on rapid-ranking methods. The Group consists of Mr David Dowrick of DSIR Physical Sciences; Dr Warwick Prebble of the Department of Geology, University of Auckland; and Mr John Gardenier of Gardenier Consulting, who will act as convener.

The Study Group will proceed as follows:

The mapping procedure would presumably follow the logic developed for QRA. First, a contour would be sketched on a map representing the extent of the immediate effect of a major incident. A legend on the map would define the hazard and describe all assumptions made. At its simplest, the contour would delineate an area within which the effect would be total, and negligible outside. For instance, in the case of an evacuation plan, only those living within the contour would need to be shifted. If the incident was related to a hazardous plant, for which a QRA study had been made, a refinement might be introduced with a further contour indicating to what extent a further fraction of the population, say children and the elderly, would need to be evacuated. Each hazard would have its own map. Each map becomes an individual risk map for that particular hazard, when an assumption regarding the annual probability of incidence is made (possibly on a what/if basis). An overlay map could then be produced by superimposing maps of different hazards (from whatever source). With some simple manipulation a risk contour map could be enumerated for any combination of hazards, and if population figures were entered, group risk could be plotted to produce a frequency-consequence (fN) curve.

3.4 Risk Perception

Risk perception has been studied in New Zealand by Janet Gough of the Centre for Resource Management. There is no 'right' view of risk. People react differently to the same risk, regardless of whether they are presented as real, statistical or predicted risks. This variation is acknowledged in the maximum/minimum parameters which some overseas authorities specify, leaving local authorities to decide what is appropriate between those extremes. Even if risk is perceived to be low, the associated hazard may be regarded as intolerable for ethical, political or other social reasons. Planning tribunals do take into account public feelings, but more weight is usually given to quantitative and technical evidence of risk.

We note that discussions at the workshop apparently confirmed that a distinction between qualitative and quantitative risk assessment is largely academic. In practice, all risk assessments start qualitatively, with quantitative input where possible and significant. Where data are available, quantitative methods merely sharpen qualitative judgements.

3.5 Risk Criteria

The Warren Centre Report advised that safety guidelines might include numerically derived risk levels as a means of fixing indicative standards of safety. Prior to the production of that report, the New South Wales Department of Planning, which operates a Major Hazard Policy Unit, had promulgated criteria for individual mortality risks from acute hazards for various land uses in that State. Criteria for the risk of injury or irritation to members of the public were also set for toxic exposures exceeding one hour. No similar guidelines have been set in New Zealand.

With few exceptions worldwide, there has not been sufficient public consensus for regulatory authorities to formally lay down particular risk levels as safety indicators. The most publicised exception is the Netherlands, where a consensus arose following a major natural disaster, a storm with floods claiming 1700 lives, which caused extensive public debate on the optimum height of protective dykes. While in New Zealand no disasters of such magnitude have taken place, the 1931 Napier earthquake with 256 victims profoundly changed existing design codes. Today's generation, although still adhering to demanding design codes for earthquakes, has not made fully adequate insurance provision for meeting their consequences. Only in recent years has this lack become a subject of public debate, reflecting a growing concern with risk in general. New legislation mainly identifies issues for consideration, stopping short of setting risk level criteria. One local authority, however, has incorporated into its district planning scheme the concept that a hazard rating should be used to determine whether or not a full safety analysis is needed to accompany any development proposal as a conditional use Perceived disadvantages of formal risk analyses lie in the assumptions embedded in any quantitative analysis of a range of mitigating factors, which may or may not happen in any given instance. Calculated risk estimates are considered difficult for a lay observer to comprehend, and this problem will not be alleviated just by introducing short-cut methods. Nevertheless, we believe that Regional Councils, or Resource Manage-ment Boards should they be formed, will seek guidelines on risk issues under the Resource Management Act 1991. A decade earlier local authorities likewise sought similar guidance in planning LPG facilities although, in that instance, draft guidelines prepared on QRA principles were not adopted by the government. We consider that the work of the proposed Study Group on Rapid-Ranking Methods will revitalise this debate and provide an opportunity to devise an indicative set of risk criteria applicable to a wide range of hazards of both natural and technological origin, including hazards formally analysed with QRA methods. We recommend that the Study Group consider this possibility.

3.6 Accident and Hazard Databases

The workshop revealed that a number of databases containing accident information exist in New Zealand. These include:

- The New Zealand Fire Service's annual review of attended incidents.
- The accident database being set up by the Occupational Health and Safety Service from visits to workplaces by field staff.
- The Accident Compensation Corporation's records of compensated accidents (accidents to persons away from work for more than one week).

- The earthquake damage database held by the Earthquake and War Damage Commission.
- Traffic accident data collected by the Ministry of Transport.

Access to information about accidents and other failures is crucial for quantitative risk assessments, but there are restrictions of access whenever incidents are subject to insurance claims, while confidential information cannot be released by government departments. A national failure database under appropriate safeguards and under control of some independent authority would address the requirements of both accessibility and confidentiality, besides providing the convenience of a single source of information. Also, a central recording office would not be constrained by limits of departmental or corporate domains of responsibility.

Participants at the workshop, however, believed that the need for such a central database was not pressing at the moment, but favoured that national guidelines on how to access existing databases be written. A Study Group was formed for that purpose, consisting of Mrs Janet Gough of the Centre for Resource Management, Lincoln University, and Professor Roger Keey of the Department of Chemical and Process Engineering, University of Canterbury, as convener.

While supporting this modest initiative we consider that the need for a national database, linked to overseas accident and failure databanks, cannot be lightly ruled out, should quantitative risk assessment become a recognised aspect of safety assessments under the new Resource Management Act and other pending legislation requiring proof of safety performance. We therefore suggest that the Study Group also collects relevant information on overseas databases.

3.7 Philosophy

As noted in the workshop's recommendations, participants took note of a suggestion to develop a philosophy of resource use and attendant hazards. An offer was accepted that this be studied by Mr Petrus Simons of Integrated Economic Services, and Mr John Gardenier of Gardenier Consulting, convener, both of Wellington.

4. Further Consultations

The trend towards self-regulation of workplaces, 'sustainable' resource development and enhanced environmental protection will require a substantial increase in experienced and skilled practitioners of various disciplines to evaluate and manage the risks of attendant hazards.

Mere legislative and administrative changes will not be enough to meet the demands of the new order. In times of severe financial constraint it will not be easy for educational institutions, industry, and statutory and regulatory bodies to ensure that adequate numbers of appropriately skilled staff are available for this work. Yet without this commitment, the less prescriptive environment of the future will be a more hazardous one.

We consider that the issues raised in the foregoing paragraph are sufficiently important to warrant further study and recommend that the Board arrange to consult appropriate persons by no later than August 1992 to establish a training policy.

Workshop participants believe that an annual event of similar format would be useful to maintain interdisciplinary contact and we recommend that this be combined with the 1992 consultation on training. The composition of the meeting would not necessarily be the same as for the 1991 workshop.

5. Project Leaders

We further recommend that one or two Project Leaders be appointed to manage the second stage of the project, culminating in a second Project Report for completion in November 1992. Project Leaders actively participate in the work of the Study Groups on Rapid-Ranking Methods and Risk Mapping, and encourage and monitor the groups' progress in dealing with Definitions, Databases and Philosophy respectively. In February 1992 they presented the 1991 project results at the IPENZ Conference which they will repeat, as required, elsewhere later in the year. They will organise the 1992 workshop for no later than August, arrange group study reports for discussion and prepare position papers on the training of risk assessment practitioners. It is possible that the second Project Report, to be submitted in November 1992, would seek approval for a third stage of the project, depending on the need for further studies.

6. Longer-term Objectives

Finally, the perceived longer-term objectives of this project are:

1. TO ensure that the Centre for Advanced Engineering actively participates in filling a vacuum caused by an increasing demand for quantitative risk assessment services.
2. TO achieve this by publishing reports on the outcome of structured enquiries into comparable risk assessment methods suitable for application in New Zealand.
3. TO actively encourage, by means of workshops, interdisciplinary dialogue on the rational management of risks.

7. Recommendations

We recommend:

1. THAT the Board meet the expenses of a Study Group on Rapid-Ranking Methods set up by the workshop to evaluate various semiquantitative methods for assessing risk levels and impacts for both natural and industrial hazards.
2. THAT the Board meet the expenses of a Study Group on Risk Mapping, set up by the workshop to produce New Zealand examples of maps showing geographical distribution of risk, regardless of whether acquired from standard quantitative risk assessments or from rapid-ranking methods.
3. THAT the Board approve the setting up by the workshop of Study Groups dealing with Definitions, Databases and Philosophy.
4. THAT the Board sponsor a further workshop, to be held not later than August 1992, to which selected persons would be invited to review the work of the Study Groups and to discuss the need for greater numbers of professionals trained and experienced in risk assessment and risk management in order to meet the requirements of the Resource Management Act 1991 and associated legislation.
5. THAT the Board appoint Project Leaders to manage the second stage of the project, due for completion by November 1992, and to present the results of the various studies in a second Project Report.
6. THAT the Board seek appropriate sponsorship to disseminate the results of both stages of the project.

Briefing Paper: GENERAL CONCEPTS OF RISK

John Gardenier

1. Introduction

1.1 This paper summarises general concepts of risk with a view to comparing, say, natural and industrial risks. These concepts were developed in the nuclear and chemical industries to evaluate major industrial hazards and proposed risk reductions, often in association with planning applications. When generalised, they could also be applied to a much wider range of man-made as well as natural risks, including occupational, public, environmental, health, financial, social, local, regional and global risks. A systematic approach, as presented here, would improve our understanding of risk and facilitate the interdisciplinary exchange of risk information.[1]

2. The Structure of Risk

2.1 Risk terminology is confused. ***Risk*** and ***hazard*** and many other ***bold italicised*** words in this paper have meanings which, in lay terms, overlap or are interchangeable.

2.2 We may define

risk as the probability of a specified loss or harm, and

hazard as a potential loss that can cause human, social, environmental or economic harm

Risk has a *consequence* component and a *probability* component. A risk increases not only with increasing *consequence,* but also when its *probability* increases. ***Risk*** is therefore sometimes defined, particularly in the American literature, as the probability of an event occurring times the magnitude of it, should it occur.

Hazard normally refers to the magnitude of the loss or harm. The *consequence component* of a risk may therefore be referred to as a hazard.

Absolute safety is the state where no hazard exists or where the probability of a hazard happening is zero. In practice, ***safety*** is the state when the hazards are known and considered to be tolerable.

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1 For the integral approach presented in this paper the author is indebted to Marshall (1990).

2.3 Distinctions can be made between:

(a) high probability/high consequence risks

(b) high probability/low consequence risks

(c) low probability/high consequence risks

(d) low probability/low consequence risks

There is general agreement that class (a) is unacceptable, while class (b) may constitute a frequent nuisance. Risk concepts presented in this paper were specifically developed for class (c) using a methodology now generally known as ***quantitative risk assessment*** (QRA) and, less commonly, as ***hazard analysis*** (HAZAN). Class (d) risks we can normally live with.

2.4 Figure 1, which shows the structure of the ***consequence*** component of risk, illustrates how a realised hazard arises through a sequence of causes and effects which can be seen as starting when a potential incident at some *source* causes an *effect* at some other place, with further *consequential* harm or loss. Simple cause and effect relations, as in the figure, may in fact consist of complex cause and effect sequences depicted as event and fault trees.

2.5 By considering the ***probability*** component of risk, Figure 2 shows how each of these steps can be seen to have their own probability. The final risk may be much smaller than the risk of its constituent parts: If the chance of p_1 of an incident occurring is 1 in 100 per year, and the chance p_2 of the resulting exposure at a certain distance is only one percent which would harm 1 in 100 (=p_3) of the population, the overall risk **(p)** of one member of the population would be as small as 1 : 1 000 000.

2.6 Both figures show how easy it is to be confused when talking about risk. Are we talking about 'the risk' at a *source* (the nature of the incident, or probability p_1)? Or about the risk at a certain sensitive location or situation in terms of immediate *effect* (say reached by fire, or probability p_2)? Or about ultimate *consequence* (loss, death, p_3)? Moreover, does the risk refer to p_1, p_2 or p_3 separately, or to $p_1 x p_2$, $p_2 x p_3$, or just to $p_1 x p_2 x p_3$? It may not be clear what someone else means when quoting a quantified risk until we check how the risk is, or should be, calculated.

2.7 Figure 3 shows that acute and chronic risks, usually considered totally different in nature and approach, can be seen to fit in an *integrated scheme*. Note that this figure only shows two typical cases. Mixed combinations are possible, for example, an accident with delayed exposure.

2.8 Figure 4 shows where in the structure of risks various disciplines involved in quantitative risk assessment have developed their own distinctive jargon, which are not further enlarged upon in this paper. Note that terms linked with recently developed QRA techniques mainly feature in the *acute risk* section, while *toxicology* mainly features in the *chronic risk* section. For further reading useful in this context see Liquid Fuels Trust Board (1984) and British Medical Association (1987). The former is a comprehensive report of a New Zealand study on LPG acute risks, and the latter a readable general text dealing in particular with chronic risks.

2.9 ***Risk management*** is concerned with the monitoring and control of hazards, with the ultimate aim of reducing either their consequences or their probabilities, or both, to insignificant numbers. Figure 5 distinguishes between *source-oriented* and *effect-oriented* risk management. The latter can only be applied where the source is not accessible or is difficult to control (earthquake, fencing of reserves, buffer zones). *Source-oriented* risk management tackles the heart of the matter and is usually environmentally preferred.

2.10 *Effect-oriented* risk management may result in transferring a hazard to a higher or lower *risk zone*. For example, high chimney stacks disperse detrimental gases over a wider area at a lesser concentration than shorter stacks (see Figure 6).

2.11 *Cost/benefit* studies for risk reduction are of limited practical use. They can only be applied for risks of the same kind, and only reflect *economic* values, and not *health* or *social* values.

3. Risk Quantification

3.1 A primary aim of risk quantification is to express risk in terms of ultimate *consequences* (damage, loss, injury, fatality, mortality). Most quantitative risk assessments to date have concentrated on human fatality risk, thus building up a common basis of measurement. Therefore risks quoted from QRA studies are assumed to refer to human fatalities, unless specified otherwise.

3.2 Ultimate ***consequence risk***, then, is calculated in two steps, starting with ***individual risk*** *if* a person happens to be present somewhere where he or she can be killed as a result of *any* incident scenario at the source. From individual risk, ***group risk*** (also called ***societal risk*** or ***community risk*)** can be calculated, based on the number of people assumed to be actually living or working around the source. Details are described below.

3.3 Formally defined, the ***individual risk*** is the probability that an *individual* person, object or function, if present in a certain location for a certain period, would be harmed by (the cumulative) risk from (all the) hazard(s) from a certain source.

Example: the risk of a person being killed at 70 metres from a large New Zealand LPG refuelling station has been calculated to be $3x10^{-5}$/yr (from Liquid Fuels Trust Board, 1984:80).

3.4 From this definition, it follows that the ***group*** (or *societal*) ***risk*** is the probability that a certain number or *group* of those individual persons, objects or functions may be *simultaneously* harmed by that (cumulative) risk.

Example: the risk of 100 people being killed by a serious accident at a large New Zealand LPG refuelling station in a built up area has been calculated to be $2x10^{-5}$/yr (from Liquid Fuel Trust Board 1984:80).

3.5 Note that probabilities in this paper are expressed in scientific notation. The value $2x10^{-5}$/yr is shorthand for 2 chances per 100,000 per year, or a chance of 1 in 50,000 per year (often 'explained' to mean *on average once each 50,000 years* or *on average once a year for 50,000 such pipelines*).[2]

3.6 To obtain risk information on non-fatal and other impacts, it may not be necessary to engage in other assessments. Depending on the nature of the risk for which the likelihood of fatalities has been calculated, it is often possible to deduce information on concurrent risks relating to injuries, property damage or environmental harm, based on reasonable assumptions, say one hundred injuries per fatality.

3.7 ***Group fatality risks*** may not need to be calculated if no *major hazards* are envisaged. Often, however, planning authorities require comprehensive individual and group risk information, especially to place *worst-possible* events in a clear perspective.

3.8 ***Individual risks*** can be drawn on a map by means of ***risk contour*** lines (see Figure 7) ; also called *effect distance* lines.

The fx diagram is a plot of *individual risks* (f for *frequency rate*) against distance x from the source. Figure 8, for example, compares the individual fatality risks of a large LPG refuelling station with those of a petrol station of comparable size. Note that each 'step' in such a graph represents a dominant accident scenario.

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2 This simple relationship between the probability and the mean return interval only holds for rare events.

3.9 ***Group risks*** are represented in so-called fN curves (frequency rate versus number in the group), also referred to as ***risk profiles***, see Figure 9.

3.10 Before probabilities have been calculated, it is possible to draw *hazard* contour maps (**not** *risk* contour maps) which link distances within which, say, 100 percent *fatalities* would be suffered as a result of a specific incident scenario at the *source*. Contours of one percent or 10 percent *fatality* may also be shown. Cumulative *individual* and *group* risks can be compiled from several such maps for incident scenarios of increasing severity, once their *probabilities* have been assessed. A description, in lay terms, of how to derive *individual* risk from *hazard* information and *group* risk from *individual* risk can be found in TNO (1983:126-144).

3.11 Where risk management is only concerned with plant reliability and on-site safety, it is often sufficient to concentrate on the risk of incidents at the *source* and their immediate *effects* without proceeding to calculate the *consequence risk*.

3.12 The nature of the risk may be such that risk does not vary with distance from the source. The source may even be dispersed.

3.13 *Individual risks* specifically calculated for a particular source are often compared with ***average individual risk*** calculated from available national mortality statistics. National ***average group risk*** statistics may be difficult to obtain from national statistics, although press reports are usually available in such cases.

3.14 *Individual* fatality risks range in order of magnitude from 10^{-3}/yr (smoking) through 10^{-6}/yr (dam failure in the US) to 10^{-10}/yr (hit by meteorite). (See Figure 12 and associated discussion in Section 4.6).

3.15 The accuracy of risk quantification has been often debated, especially in the late 70s and early 80s, when QRA was still in its early stages. This refers to *uncertainty* , the extent of which may be quantitatively assessed with a *sensitivity analysis.* Experiences, though, with audits of quantitative risk assessments have shown that assessments of the same risks prepared by different bona fide analysts reasonably agree with each other. For New Zealand audits, see Keey (1981), Liquid Fuels Trust Board (1984), and SAVE Consultants (1987). However, when comparing risk levels from different sources it makes sense to round them off to an order of magnitude such as 10^{-4}/yr, 10^{-5}/yr. Essentially, risk levels of, say, $6x10^{-5}$/yr and $8x10^{-5}$/yr and should be considered the same.

3.16 In occupational and health areas several other risk indices are in use which, in fact, are fully compatible with *individual risk*. Conversion from one type of index to another should be as automatic as changing miles into metres. (See Figure 10.) Note that *FAR* units express individual risk in frequency *per hour* instead of *per year*. Note also that ***lost-time frequencies*** do not relate to fatalities, but to job injuries (not reporting for duty early next day) and, likewise, that ***dose concentrations*** (often) relate to quite unacceptable exposure short of causing death.

4. Risk Perception

4.1 ***Risk perception*** is about *risk tolerance* by society: in other words, when do people find risk acceptable, not acceptable, or tolerable? Risk *perception* cannot be sensibly discussed without being reasonably familiar with risk *quantification*. While risk *quantification* has not provided a magic formula to reach an easy consensus on what is acceptable, it allows the problems associated with risk *perception* to be placed in perspective.

4.2 Social research on risk perception has so far been mainly qualitative. Figure 11 lists the factors influencing people's perceptions of risk.

4.3 Only the first item of Figure 11 (people are less inclined to accept involuntary rather than voluntary risk) has received much quantitative attention by analysing risk levels available from national statistics. Other items listed in the table may be just as important.

4.4 Planning proposals for hazardous installations are, in particular, affected by Item 26, Figure 11 (risks are less acceptable if they are not applicable to everyone).

4.5 ***Catastrophe aversion***, identified in Item 8 Figure 11, requires some extra attention. Based on the traditional formula that the extent of the hazard *times* the probability thereof should be *constant*, it has generally been assumed that, if the risk of a certain size and probability appears to be acceptable, a size n times larger would only be acceptable with a probability n times smaller. Risk perception studies have shown that for major hazards this is not sufficient: the probability would need to be $n^{1.5}$, n^2, or even n^3 times smaller to satisfy people's catastrophe aversion — see also Section 5.5 and Figure 14 below (Ministry of Housing Physical Planning and Environment, 1986).

4.6 Results of an early example of quantitative risk research are summarised in Figure 12, analysing agreement/non-agreement between authorities and public on risk matters. The chart shows that in the 1970s disagreements between governments and people in Western Europe about the acceptability of existing risk levels covered an astonishingly wide range of risk levels: from as high as 10^{-3}/yr to as low as 10^{-8}/yr. Substantial psychometric research (Gough 1990:34, and Vlek & Stallen 1979) seems not to have taken place in recent years.

4.7 Risk perception research seems to have much in common with market research. People do not necessarily accept good products at reasonable cost price. Responsible product and price advertising is a legitimate form of influencing the market. Likewise, the publication of quantified risk information is a positive contribution to the social debate on environmental risks, although the merest hint of 'advertising' may rebound.

5. Risk Criteria

5.1 ***Risk criteria*** are formally adopted rules specifying *quantitatively* defined *allowable* risk levels. In quality control jargon, safety regulations which do not specify allowable risk levels do not set *performance* standards.

5.2 ***Non-quantitative risk criteria*** like ALARA and BPO (see Figure 13) are practical open-ended requirements. Lowest risk alternatives can only be properly evaluated with *quantitative* risk assessment. Such non-quantitative criteria make particular sense when used in conjunction with quantitative criteria (safe is never safe enough).

5.3 ***Quantitative risk criteria*** should specify at least *maximum allowable* risk levels. They set *minimum safety performance standards.*

5.4 When risks are socially sensitive, *maximum allowable* risk criteria may be challenged. A safety authority may then find it prudent to define a *desirable target level,* say two orders of magnitude lower than (or one percent of) the maximum allowable risk level. If the target level is achieved, no challenges would be upheld. Risk levels between target and maximum allowable values may be negotiated between interested parties.

5.5 This model, defining maximum allowable and desired target levels, has been formally adopted in the Netherlands, the only country to have done this so far (see Figure 14). Note how the Dutch deal with *catastrophe aversion.*

5.6 Alternative approaches stemming from Anglo-Dutch risk-assessment developments have been applied, usually on an *ad hoc* basis, in other countries, particularly in Scandinavia, Hong Kong, Singapore and Australia.

5.7 Figure 15 shows criteria adopted in New South Wales for a particular area with existing developments, specifying a variety of maximum allowable risk levels ("not to be exceeded") for individual risk, including occupational risk. Australian authorities generally allow less public involvement in formulating planning procedures than is the case in the Netherlands and New Zealand.

6. Applications

6.1 Planning authorities usually consider QRA an important quantitative tool to balance risks against costs, benefits and welfare aspects of potentially hazardous proposals. QRA is also used to report on the nature and size of risk reductions for alternative siting proposals. *Individual risk* contours help to plan the layout of surrounding areas. Graphical *individual* and *group risk* information may be used to inform surrounding populations of public risk, and especially to place worst-case hazard scenarios in perspective.

6.2 Sociologists would be able to provide useful background information regarding the perception of quantified risks by reporting on details of psychometric research.

6.3 The chemical and petrochemical industries have used QRA extensively for design purposes, and likewise have applied it to achieve improved plant reliability. For planning purposes, an assessment of off-site hazards, risk contour plans and group risk profiles is usually required. Regular safety audits are often undertaken to confirm that safety standards and agreed risk levels are being maintained. Of considerable interest in New Zealand is recent work on the ranking of industrial risks based on simplified risk assessment methods. Such work (Palmer 1990, Wood & Tweeddale 1990, and Keey 1991) deserves to be reviewed with a view to producing 'risk-guestimates' in terms of the general concepts promoted in this paper.

6.4 The aim of applying QRA to seismic hazards would be to prepare *risk contour plans* and *group risk profiles* for some major earthquake scenarios of a built-up area. Although nothing can be done to prevent an earthquake at its *source,* an *effect-oriented* analysis is possible, which may assist engineers and planning and civil defence authorities to mitigate or minimise the effects of an earthquake. Hazards with a more deterministic effect, such as coastal erosion, enable simple guidelines to be prepared for risk avoidance. Similar observations can also be made regarding volcanic hazards.

6.5 For flood-prone areas it should be possible to prepare more reliable risk contour plans than for earthquakes. Although New Zealand floods seldom reach roof tops, for mutual comparison with other risks consideration also needs to be given to *fatality* risks;

however, local interest focuses mainly on individual and group *evacuation* risks, for which contour maps might be drawn.

6.6 Consequences of dam failure can be expressed on maps featuring fatality as well as associated evacuation risk contours.

6.7 Although the risk implied in structural engineering design and construction is not often challenged (except for negative publicity relating to incidental on-site construction accidents), engineering structures are often used to reduce natural risks, suitable for QRA analysis. Also, in itself, the possible failure of an engineering structure constitutes an *individual* and *group* risk in or around the structure.

6.8 QRA studies can be applied by transport authorities overseas, especially to select compulsory routes for the transport of dangerous goods, or for studying transport alternatives by road, rail, coastal tanker or pipe line (Liquid Fuels Trust Board 1984, pp.86-110). *Individual risk* contour maps of stretches of major access roads or railways to large industrial areas through built-up areas, may show dangerously high risk levels. A characteristic of hazardous transport is that in *group* risk the size of the group depends on the length of the road under consideration; that is because the *individual* risk contours are open-ended, with the actual number of people caught between these contours increasing with the selected length of the road. The solution is to measure risks on a unit length basis (deaths per km per year), or to define the risk for specified stretches of road.

6.9 Property loss associated with any of the major risks discussed here is related to fatality risk, and individual damage contours can be compiled separately from that information. Damage profiles or *fA curves* may be plotted to show calculated frequencies of areas A of increasing size being damaged to a specified extent.

6.10 The insurance industry may use QRA studies to assess whether introduced risk reductions are large enough to consider a revision in premiums. In this case f$ curves can be plotted, showing frequencies against increasing amounts to be paid out. An integrated f$ profile could be produced for a given insurance company.

6.11 Economists can apply risk concepts to issues involving economic risk (and uncertainty), especially where monetary *consequence* components are allowed to be *n* times higher, provided that corresponding *probability* components are at least *n* times lower. *Catastrophe aversion* may apply to corporate financial management.

6.12 The QRA methodology is particularly suited to address fire service issues like the optimum number of fire sprinklers to be installed over a given area, or the distribution of fire stations required in large urban areas.

6.13 Health and Civil Defence issues arising from potential local disasters can be analysed with *individual* risk contour plans from which *group* risk profiles can be derived as a basis for establishing priorities for emergency hospital and rescue services.

6.14 Pollution of the atmosphere and the discharge of wastes often have environmental impacts which may be represented as *individual risk contours* and *group risk profiles* for purposes of discussion or negotiation.

6.15 Environmental risk assessment is in its early stages of development in New Zealand and overseas. A seminal Dutch White Paper (Ministry of Housing, Physical Planning and Environment 1988/89) has defined *collective risk for ecosystems* as the likelihood per year that an ecosystem will suffer a particular harmful effect as a result of exposure to an agent.

Conclusion

The general risk concepts presented in this paper address risk quantification. Risk quantification is an essential part of quantitative risk assessment (QRA) which, to date, has been essentially restricted to the management of hazardous industrial risks, mainly involving chemical and planning disciplines. A logical next step would be to extend the number of disciplines involved, allowing risks in the widest possible sense, including natural and financial risks, to be quantitatively compared.

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Figure 1 - STRUCTURE OF THE CONSEQUENCE COMPONENT OF RISK(*)

SOURCE	EFFECT	CONSEQUENCE
INCIDENT A RELEASE X	EXPOSURE Y	CONSEQUENCE Z
(cause)..............(effect)		
	(cause).....................................(effect)	
(cause)....................(effect)		

(*) *Consequence component* may also be referred to as *hazard*

Figure 2 - STRUCTURE OF THE PROBABILITY COMPONENT(*)

SOURCE	EFFECT	CONSEQUENCE
	RISK LEVEL R = $p_1 \times p_2 \times p_3$	
the *chance* p_1 that *quantity X* of an agent (matter or energy) would be released as a result of an *incident A*	related to the *chance* p_2 that (part of) this agent would subject a sensitive body in a given location or situation to an *exposure dose* Y	related to the *chance* p_3 that this exposure dose would cause an *impact Z* on that body - person/ animal/plant/ecosystem/ property

(*) *Probability component* is often called *risk level*

Figure 3 - STRUCTURE OF ACUTE AND CHRONIC RISKS

SOURCE	EFFECT	CONSEQUENCE
serious accident A immediate impact Z large release X chance p_3 small chance p_1	**TYPICAL ACUTE RISK** exposure dose Y chance p_2	
slow release A small X chance p_1 = 100%	**TYPICAL CHRONIC RISK** exposure rate Y measurable on location chance p_2 = 100%	delayed impact Z and chance p_3 (Z = 0 for exposure rates below safe threshold level, (if applicable)

Risk management endeavours to control A, X, Y, Z, p_1, p_2 and/or p_3.

Figure 4 - GENERAL RISK TERMINOLOGY

SOURCE	EFFECT	CONSEQUENCE
incident hazard loss of containment	extent size radius of action	impact
ACUTE HAZARDS/RISKS		
accident loss of containment fire explosion *hazard analysis (HAZAN)* probability* *event trees* *fault trees* *risk assessment (QRA)*	exposure probability* exposure dose/rate group/societal risk	acute harm direct damage probability* or risk level individual risk
CHRONIC HAZARDS/RISKS		
release emission contamination radioactivity	exposure exposure rate/dose concentration radiation dose epidemiolo-	loss of health (delayed damage) (individual risk) (group/societal risk) -gical tests

* *Probability* also called *chance*, *likelihood*, *frequency*, 'risk'

Figure 5 - SOURCE AND EFFECT-ORIENTED RISK MANAGEMENT

SOURCE	EFFECT	CONSEQUENCE
incident *prevention*	effect *limitation*	
		Consequence *mitigation*

<<- - -<- - - --<-- -SOURCE-ORIENTED RISK MANAGEMENT<- - -<-- - --<- - -

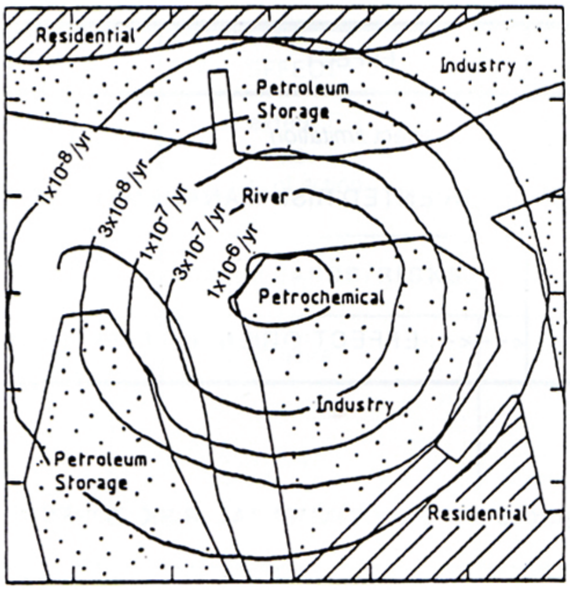
<<- - -<- --<-- -EFFECT-ORIENTED RISK MANAGEMENT<- - -<--

Figure 6 - ENVIRONMENTAL RISK ZONES

local -
regional -
catchment-
continental -
global
CONTINENTAL AREAS

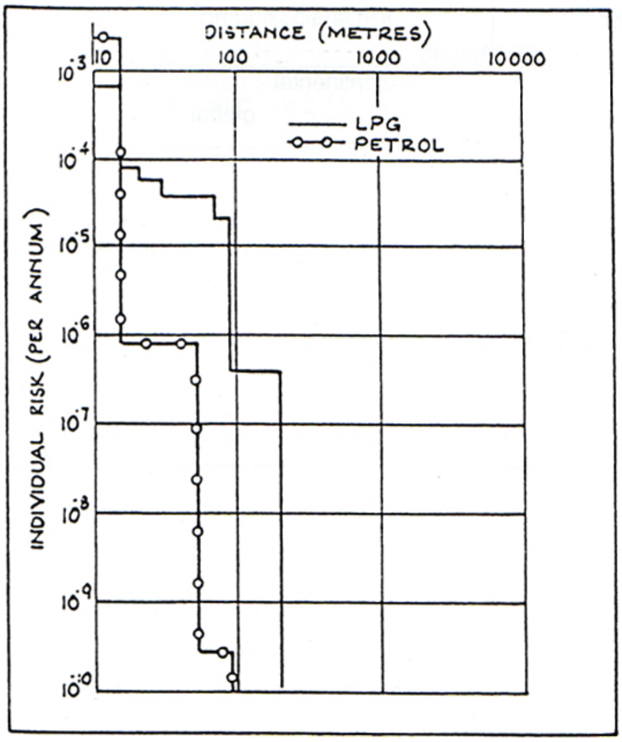
local -
regional -
catchment-
national -
oceanic -
global
OCEANIC AREAS

Figure 7 - INDIVIDUAL RISK CONTOURS AROUND A PETROCHEMICAL PLANT



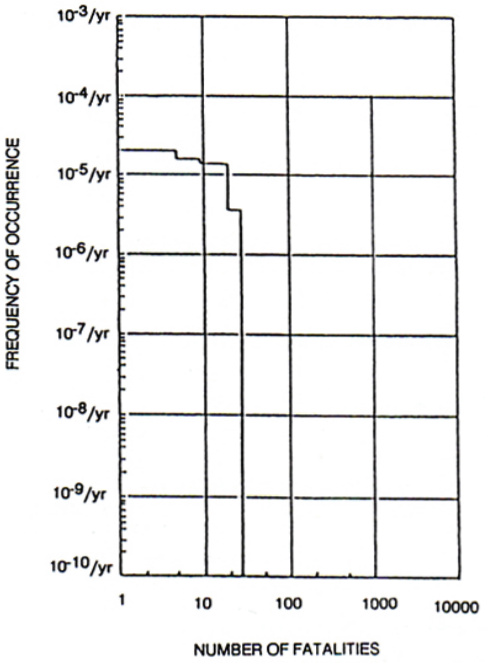
(Coran 1986)

Figure 8 - INDIVIDUAL RISK DIAGRAM or F/X CURVE



Comparison of Individual Risk at LPG and petrol refuelling stations in NZ (LFTB 1984)

Figure 9 - GROUP RISK PROFILE or F/N CURVE



Group Risk Profile of LPG Pipeline (LFTB 1984)

Figure 10 - COMMON OCCUPATIONAL/HEALTH RISK INDICES

- **LOST-TIME FREQUENCY** = number of lost-time work-related accidents per 100 thousand man-hours (approx number of hours worked per working career of 50 years)
  = 10^{-5}/hr = 10^{-1}/yr while at work
- **FATAL ACCIDENT RATE (FAR)** = number of fatal work-related accidents per 100 million man-hours (approx 1000 working lives)
  = 10^{-8}/hr = 10^{-4}/yr while at work
- **LOSS OF LIFE EXPECTANCY** = number of years lost in average life expectancy, based on life expectancy studies showing that, on average, one year loss equals 347 deaths per million career years
  = FAR 17 = 1.7×10^{-7}/hr = 1.7×10^{-3}/yr while at work
- **DOSE** = cumulative concentration in units of concentration x exposure time, (whereby *concentration* is the quantity of harmful substance per unit of surrounding quantity, often expressed in parts per million). This indirect measure is assumed to be proportional to individual risk, unless there is a threshold value* below which that risk is harmless.

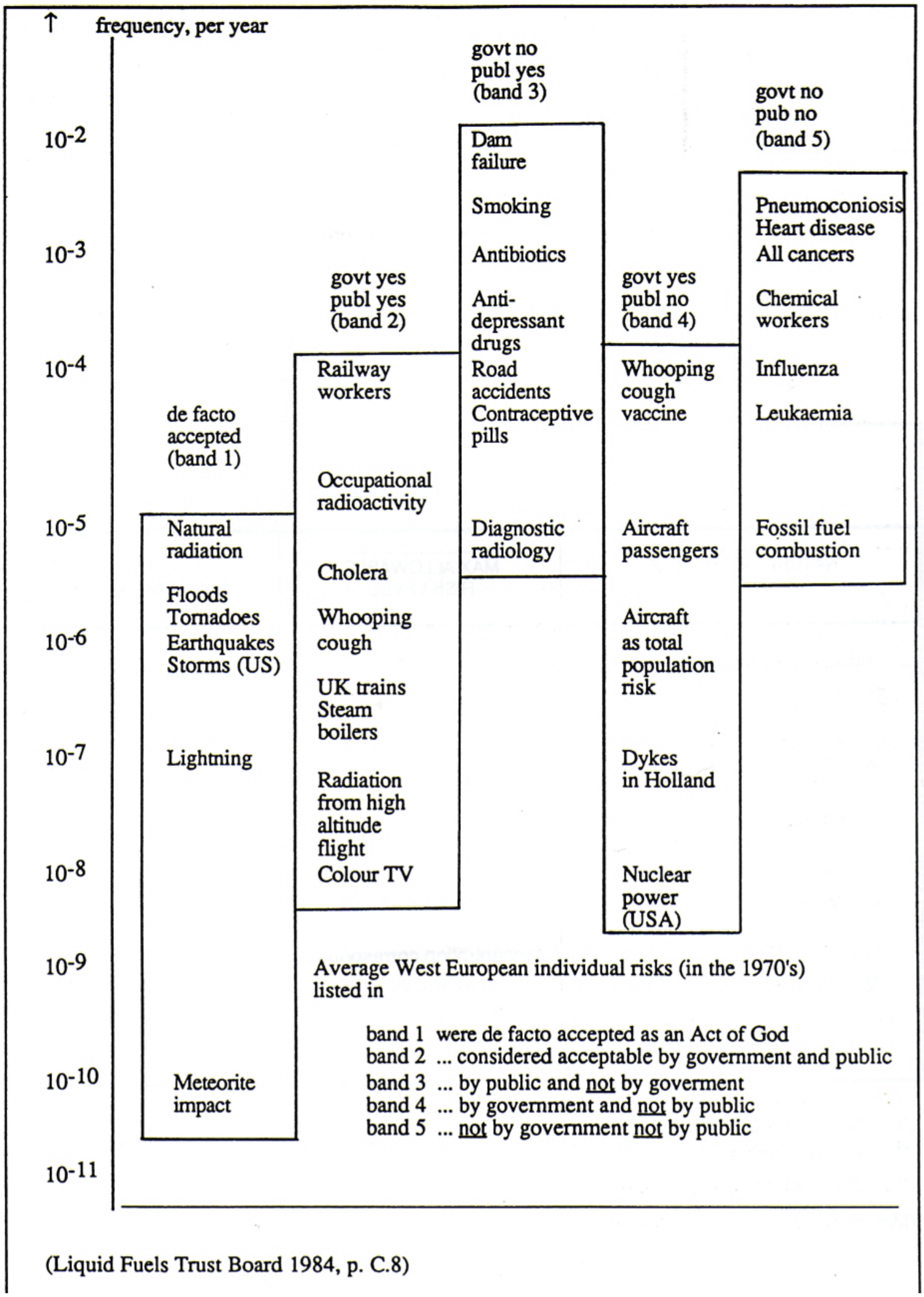
* an observed 'no effect level' (often based on animal studies) divided by a suitable safety factor

Figure 11 - FACTORS AFFECTING PEOPLE'S PERCEPTION OF RISK

1	risk taken voluntary - involuntary
2	consequence of risk immediate - consequence delayed
3	risk familiar - not familiar
4	risk known to science - not known to science
5	risk under some personal control - no personal control
6	type of risk experienced before - not experienced before
7	consequences not cumulative - clearly cumulative
8	consequences not so serious - catastrophic
9	consequences common - dreaded
10	consequences light - severe
11	few people exposed - large group exposed
12	substantial benefits - hardly any benefits
13	future generations not affected - definitely affected
14	low personal exposure - high personal exposure
15	contribution to global catastrophe unlikely - envisaged
16	character of risk remains the same - is changing
17	risk reduction possible - not possible
18	alternative process or activity possible - not possible
19	exposure necessary - not necessary
20	occupational exposure - not occupational
21	affects people occupationally - affects public
22	no misuse envisaged - likely misuse
23	consequence reversible - not reversible
24	social attitude to risk remains the same - is changing
25	personal attitude to risk remains the same - is changing
26	same risk applicable to everyone - not to everyone
27	risk away from home - involuntary risk at home
28	risk at work, sport, travel - at home, nursery, hospital

(Gough 1990:30 amended)

Figure 12 - PUBLIC VERSUS GOVERNMENT RISK ACCEPTANCE



(Liquid Fuels Trust Board 1984, p. C.8)

Figure 13 - QUALITATIVE RISK CRITERIA

ALARA principle in the nuclear industry 'As Low As Reasonably Achievable' **BPO approach** in NZ Resource Management Bill 'Best Practical Option'

Figure 14 - EXTERNAL (*) RISK CRITERIA IN THE NETHERLANDS

HUMAN RISK CRITERIA FOR NEW DEVELOPMENTS(**)
(NEL = no effect level; SF = safety factor)

NATURE OF THE RISK	MAX ALLOWABLE RISK LEVEL	NEGLIGIBLE RISK LEVEL
individual risk resulting from effects without threshold value	10^{-6}/yr	10^{-8}/yr
group risk chance of accident with 10 deaths	10^{-5}/yr	10^{-7}/yr
a group consequence n times greater must have a corresponding chance at least n^2 times smaller (***)		
risk of health consequences resulting from effects with a threshold value	concentration corresponding to NEL/SF	1/100 th of concentration corresponding to NEL/SF

(*) Not applying to occupational risk
(**) For existing hazards 10x higher risk levels are allowed
(***) This addresses catastrophe aversion

(Min. of Housing Physical Planning and Environment, 1986:164)

Figure 15 - INDIVIDUAL RISK LEVEL CRITERIA IN NEW SOUTH WALES

ACUTE RISKS (NEL = no effect level; SF = safety factor)	
LAND USE	RISK LEVELS SHOULD NOT EXCEED
residential	$1x10^{-6}$/yr
open space - passive	$1x10^{-5}$/yr
- active	$5x10^{-6}$/yr
commercial	$5x10^{-6}$/yr
public roads	$2x10^{-5}$/yr
industrial	$2x10^{-5}$/yr
TOXIC EXPOSURE (exceeding one hour)	
DEGREE OF PUBLIC EXPOSURE	RISK LEVELS SHOULD NOT EXCEED
exposure causing injury	$1x10^{-5}$/yr
exposure causing irritation	$5x10^{-5}$/yr

(NSW Department of Environment and Planning, 1985:8-9)

Briefing Paper: RISK ASSESSMENT METHODS

Roger B Keey

1. Introduction

This paper presents an overview of the methods used to determine risks quantitatively.

2. Assessment Methods

2.1 The rapid growth of industrial activities worldwide has resulted in many concerns regarding the sustainability of these developments, the conservation of resources, and energy use and environmental protection. Not the least have been worries about the safety of large processing plants containing huge inventories of flammable or toxic materials. Although the accident rate due to such process-related hazards is normally less than that for many other kinds of mishaps, certain spectacular incidents involving tragic loss of life and massive damage to facilities have heightened public awareness of these risks. Public outcry after such incidents has often led to formal inquiries resulting in new regulatory proposals for safety assurance. New Zealand has not been exempt from this development (Advisory Council for Occupational Safety and Health, 1988). A review of Australian, European and USA legislative policy regarding major hazard control is given by Haddad and Kanga (1986). Changes to offshore regulatory practices in the United Kingdom sector are likely following the recommendations of the Cullen Inquiry into the disaster on the Piper Alpha oil platform in the North Sea (Boniface, 1990).

2.2 Brown (1979) notes that it is often difficult to assess the risks of technological advance, nor is it easy to decide what level of risk should be tolerated. A potential conflict between perceived risk and calculated risk arises from differing values and may be resolved by compromise between parties (Gough, 1988a). Public perception and response to risk assessment in New Zealand is surveyed by Boshier (1990). It is claimed that people, generally, have difficulty in imagining that potential dangers such as floods could be much larger than those previously experienced, whereas authorities concerned with hazard control regard natural events to be random and indeterminate: the longer the timespan between events, the larger the event.

2.3 Process-related hazards may be assessed by reference to the chemical nature of the materials being processed, the kind of operations employed and the extent to which working conditions deviate from ambient (Palmer, 1990). More generally, industrial hazards can be related to the frequency with which mishaps may escalate into significant accidents should mitigating features be absent, or when there are deficiencies in the response to a consequential accident, should it happen (Wood and Tweeddale, 1990). This approach has been used to survey the safety standards in an industrial area of West Auckland. Natural hazards are normally specified in terms of the mean return interval of a specified event based on historic or geomorphological data.

2.4 Whenever accidents are common, their frequency can be adjudged on the basis of past experience. The likely incidence of rare events must be synthesized from the more frequent minor mishaps and failures which may propagate under adverse conditions into accidents of greater impact. Logic diagrams such as event and fault trees are used to trace the pathways of failures (Henley and Kumamoto, 1981). In New Zealand, fault-tree methods have been employed to evaluate a proposed nationwide system for the bulk transport and storage of liquefied petroleum gas (LPG) (ADL, 1981; Liquid Fuels Trust Board, 1984) and to determine the possible hazards from a proposed irradiation plant (Gardenier, 1990). However, the available databases on past failures, although improving, will always be inadequate to some extent as standards and environmental conditions are continually changing. For this reason the use of other techniques, such as hazard warnings, has been proposed to gauge the remoteness of a particular hazard (Lees, 1982; Keey, 1986). The prevalence of smaller-scale accidents, in which little or no harm results, provides an indication of the potential for a major incident. The hazard-warning structure provides information on the scope of strategic and tactical action required to prevent the outbreak of a major accident.

2.5 The severity in outcome, should a major hazard occur, is normally expressed in terms of probable consequential fatalities, if any, to workers and the surrounding public. For over a century mortality statistics have provided the basis for the quantification and evaluation of risk (Fox, 1981). This convention enables various types of accidents to be compared, on the assumption that the incidence of fatalities reflects the likelihood of all kinds of injuries. This method enables the riskiness of various activities to be compared on an equal contact-time basis (see Keey, 1987). A summary of some published guidelines on fatality-based risk limits is given by Stephens (1986).

2.6 Work-related fatalities have in general been well documented and analysed. The average individual risk of a work-related fatality for New Zealand conditions is 7×10^{-4} per year (1981 figures). Off-site deaths due to process-related accidents, even for industries with high hazard potential, are unlikely to occur mainly because of the small scale of New Zealand industries, their sensible siting and low surrounding population densities. Major natural disasters (such as very large earthquakes or volcanic events) that may result in deaths have mean return intervals of many orders of magnitude greater than process-related accidents which would yield offsite deaths. Both the dust explosion at Masterton in 1965 and the steam explosion at Seaview in 1975 were deemed sufficiently serious for courts of inquiry to be set up to determine the causes of these accidents, but neither resulted in off-site deaths. Fatalities to the public are therefore not the sole matter of concern. Frequent floods in New Zealand rarely kill people, although stock and property losses may be substantial. Wood and Tweeddale (1990) use a mixed-unit severity scale to judge hazard levels, with injuries and nuisance ranked as fractional fatalities. In the United Kingdom, the Health and Safety Executive (1989) has now adopted the concept of a dangerous dose (whether it be a concentration of a toxic chemical, a thermal radiation intensity or an explosive overpressure over a certain exposure time). Keey (1991) has proposed a criterion the number of persons significantly affected by the mishap, either through medically treated injury (and in extreme cases, death) or through annoyance by prolonged disturbance to lifestyle or from evacuation. The criterion is not limited to evaluating rare process hazards alone; it can also be applied to events with which observers are more familiar.

2.7 Gough (1988b) notes that environmental impact audits and risk assessments have closely similar methodologies and may be regarded as twin aspects of environmental risk management. Wood and Tweeddale (1990) and Zach (1990) show how existing risk indices may be used to evaluate environmental hazards, but the assessment scale involves judgemental values on the relative detriments of various possible adverse impacts. In seeking a preferred option for development, Gough (1989) suggests that feasibility and the likely degree of protection offered to human health are the principal criteria.

2.8 Vulnerability of persons to excess heat, toxic chemicals and disease is normally represented by probit relationships which express the probability of a specified injury on exposure to a given dose (see Lees, 1980, for example). The published probit relationships, even for exposure to common toxic gases such as ammonia and chlorine, are subject to considerable uncertainty (Thompson, 1987) because people have varying susceptibility and various probabilistic factors exist, such as the degree of protection afforded in any given instance. For industrial exposures, safe working conditions are related to threshold limit values of harmful substances, on the assumption of an eight-hour workday and a five-day work week. These limits are based on workplace experience (see Acheson and Gardner, 1981, for example) and extrapolation of the results of tests on animals. Large safety factors are incorporated because the sensitivity of species differs and simple scale-up criteria, such as dose-response per unit lung area or body weight, are inadequate. Exposures to the public are normally assumed to be continuous, with an added safety factor to take into account hypersensitivity. Where adequate epidemiological data exist, long-term health hazards can be rated in a similar way to acute industrial dangers on the basis of exposure time (Kletz, 1983).

2.9 In assessing public health risks from contaminated environments, Wood *et al.* (1991) note that in some cases where the exposure of people is only for limited periods, such as bathing in polluted waters, higher concentrations of harmful substances than threshold limit values might be tolerated. The exposure of aquatic biota would, however, be continuous, although only a fraction of contaminants might be taken up by a particular species.

2.10 The environmental fate of contaminants in waterways is varied. Organic compounds in anaerobic sediments may degrade slowly, whereas very volatile substances can evaporate. Metals such as copper are readily adsorbed by sediments to form metallo-organic complexes (Davis and Leckie, 1978), while mercury and arsenic compounds can be transformed microbially to extremely toxic substances (Wood, 1974). The range of reactions and numerous uptake mechanisms pose difficulties in setting safe limits.

2.11 Hazards alter with technological change, and so do our thresholds of tolerance. There have been many attempts to weigh the risks of development against the balance of benefits. Bowen (1976) has argued that technological change has caused an increase in life expectancy, and that further benefits might be traded for some lesser increase. The argument is specious (see Keey, 1982), but risk-benefit analyses may have a place when options for risk reduction are being ranked. Examples include road improvement schemes and flood protection works (Koutsos and McBryde, 1991). In comparing alternative water supply schemes, Bogardi *et al*. (1989) use fuzzy measures of costs of control and associated risks to generate a composite risk management index. The preferred option is one that most closely approaches the ideal situation of zero cost and zero risk.

2.12 Procedures that have been used in New Zealand to assess economic risks associated with agricultural projects are described by Bell (1977). Recently, Allen (1991) has outlined the use of decision trees and the handling of risk in economic evaluations. In economic risk analysis possible risks and rewards are weighed against each other so that a project decision becomes a calculated risk — an estimated chance of a loss.

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RISK ASSESSMENT — THE CIVIL DEFENCE PERSPECTIVE

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In civil defence planning we must consider what threatens public safety, with our emphasis being people before property. We must therefore consider THREATS, of which there are dozens, most of which do not directly concern civil defence planners.

Our main concerns are:

NATURAL HAZARDS	TECHNOLOGICAL HAZARDS
• Climate	• Hazardous Materials
• Tectonic	• Major Accidents
• Biological	• Structural Failures
• External (space)	• Armed Conflict

We may have, for example, an earthquake THREAT/HAZARD (these terms are used somewhat interchangeably).

In which case we would ask ourselves: What risk does an earthquake hazard have for a given community unit? Such questions comprise the ***hazard analysis*** step of civil defence planning.

We therefore consider risk as follows:

The earthquake

THREAT	=	EFFECT on: household organisation community	x	PROBABILITY % chance of occurrence in a given time period

expressed as: NIL, LOW, MEDIUM, or HIGH.

The Problem

1. Assessment of risk is subjective and therefore open to different interpretations, which may result in differing action plans for mitigation, preparation, response and recovery.
2. Our target audience includes both:
   - those who easily understand what we are saying PLUS
   - those who do not (or will not).

RISK ASSESSMENT AS A TOOL FOR ENVIRONMENTAL MANAGEMENT

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1. Introduction

The Parliamentary Commissioner for the Environment's Office was established in January 1987 to provide an independent check on the performance of the environmental management system put in place by Government. The Commissioner also has a function to provide an independent check on the performance of public authorities in undertaking their environmental management responsibilities.

When the Commissioner's Office was established there were still some development proposals that required auditing under the Government's Environmental Protection and Enhancement Procedures. The Commissioner agreed to audit these proposals. The audit provided an independent opinion on the information supplied in each environmental impact report (EIR) and, where necessary, additional information was included in the audit.

In order to assess the effectiveness of public authorities in meeting their environmental planning and management responsibilities the Commissioner has reviewed the environmental impact assessment processes they use. There are many instances where risk assessment could be applied to the management of environmental risks arising from both industrial developments and natural hazard mitigation. Past experience of auditing development proposals has also highlighted the importance of risk assessment techniques in assessing safety management of hazardous activities. Thus risk assessment techniques are regarded as an important aspect of the overall environmental impact assessment process.

2. Experience of the Parliamentary Commissioner for the Environment's Office

There have been special investigations and audits conducted by the Commissioner's Office where the use of a risk assessment approach has been recommended.

One such investigation was of the system used to assess environmental risks relating to the importation of exotic species into New Zealand. The Animals Act 1967 did not have any process in place to identify the environmental and/or ecological risks associated with new species, for example, marron, a freshwater crayfish. Changes have since been made to the Animals Act 1967 to ensure that decisions on the importation of exotic species have regard to environmental consequences.

The Commissioner's auditing of the Maui Stage Two Development coincided with the Piper Alpha tragedy in the North Sea Oilfield. Advice from Lloyds Register drew attention to the lack of a formalised risk assessment which could include both qualitative and quantitative assessment of the risks to personnel, local population, ecology and property, and is best addressed at an early stage of a project development. A recommendation was made to the Minister of Energy (as the regulatory agency) to develop an approach to safety that will be used in assessing offshore installation safety during certification of the offshore platform.

Following the Bola storm in March 1988 the Commissioner was requested to examine the effectiveness of current policies for flood mitigation. This storm highlighted the risk from flooding faced by many communities in New Zealand. Flood mitigation has worked together with land use planning in the past: flood control schemes, stopbanks, channel works, together with land use planning measures, are all measures designed to achieve risk reduction. The Commissioner concluded that regions must play a greater role in assessing risks from natural hazards, and must also identify both the generators of risk and the bearers of risk. Identification of risk generators and of the beneficiaries of any risk reduction measures should assist in setting funding for such measures. Not only is flood mitigation a subject of risk estimation; practical benefits can be derived from devising equitable funding arrangements.

3. Resource Management Act 1991

It is not only past experience of environmental management that has led to the Office's interest in risk assessment; the passing of the Resource Management Act will affect the use of such techniques in the future.

In dealing with development proposals the Resource Management Act will focus on the effects of a development. Applicants for a resource consent will, presumably, have to provide sufficient documentation on predicted effects on the (total) environment to satisfy the regulatory agency that the effects are either insignificant or can be mitigated to 'acceptable' levels. There will be instances where an assessment of either the source risk or the effects risk should be included in a resource consent application. Public authorities may have to use risk assessment techniques more extensively to weigh up the advantages and disadvantages of each proposal.

4. Techniques of Risk Assessment

Risk assessment comprises two aspects — risk estimation and risk evaluation, both of which should be considered in the decision-making process. Techniques for risk estimation range from a quantitative risk assessment (QRA) to a more qualitative assessment. To some extent the size and nature of the activity and the environment being assessed can dictate the most appropriate analytical tool to be used. The lack of technical data for New Zealand's applications may hinder the use of QRA in the near future.

The risk evaluation aspect of risk assessment is considered important because of the influence of both the interpretation of risk information by the public, and the perception of risk by the public, on subsequent decisions. Sometimes the perception of risk of environmental damage can be sufficient for the affected public to reject a development proposal on this aspect alone. There can be fundamental differences in the perception of risky technologies by the public and by technical experts.

Some limited analysis of the benefits of using a risk assessment technique to assist local authority decision-makers has been carried out by the Commissioner's Office using the Seaview LPG Depot proposal and the Ansell-Steritech proposal as case studies. In the case of the Ansell-Steritech proposal the perception of risk was related not only to the proposed location on the shores of the Manukau Harbour, but also to more global issues such as whether the proposal conflicted with New Zealand's 'nuclear-free' image. Local authority decision-makers drew quite heavily on the risk assessment studies in formulating their decision to refuse planning consent for the proposal to proceed.

The Seaview LPG depot case study revealed risks that local communities were already aware of , for example, the closing of a main access road because of storms at high tide, or the hazard of fire in bush adjacent to the communities. An LPG depot was regarded as an additional risk factor that these communities did not want imposed on them.

Ultimately, the Commissioner and the public are interested in risk estimation information and risk evaluation information being translated into risk management decisions .

RISK IN THE ROAD SAFETY AREA

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1. Introduction

Traffic accidents are the end result of millions of interactions between various vehicles in the traffic stream. Whenever different vehicles interact there is a finite but small risk that the interaction will result in some sort of accident involving property damage. Similarly, there is a risk that property damage accidents may involve death or injury. In New Zealand about three accidents involving fatal injury occur per thousand million vehicle kilometres driven. This adds up to an individual risk per year in the order of 1 in 3000, which is in the voluntary risk area where one would expect it. These rates for New Zealand are broadly similar to those in other developed countries.

2. The Implementation and Planning of Road Safety Programmes

The work of the traffic safety professional involves taking steps to prevent accidents happening, and to minimise the damaging consequences of those that do happen. The interface of traffic accidents and road safety programmes can be represented by the matrix shown in Figure 1.

Figure 1 - A Possible Range of Road Safety Interventions

	Safer People	**Safer Vehicles**	**Safer Roads**	**Safer Systems**
PRE-EVENT	Mass media campaigns	Warrant of fitness	Road design and markings	Enforcement of legislation
EVENT	Wearing seatbelts	Fitting seatbelts barriers	Construction of road-side standards	Legislation e.g. vehicle
POST-EVENT	Public education	Emergency services	Access to accident	Medical treatment and rehabilitation

This matrix, taken from a road safety plan for New Zealand recently produced by the Government (Officials' Committee on Road Safety, 1991), divides the accident event into three phases: pre-event, event and post-event. Examples are then given of the types of road safety interventions which may be appropriate to the different phases. The road safety plan maps out a direction for the next decade based on the principle of striving for safer people, roads, vehicles and systems, and discusses various possible measures and their relative priorities.

3. Risk Quantification

3.1 Macroscopic Scale

At the macroscopic level risk is normally quantified by accident rates in three ways:

Accidents per capita

This rate basically tells us how road safety looks if viewed as a public health problem. Developed countries with well-travelled populations, such as New Zealand or the USA, come out badly using this rate.

Accidents per vehicle

This is a transport demand rate which uses vehicles as a measure for transport demand. Well-travelled countries like New Zealand or the USA come out well using this rate.

Accidents per vehicle kilometre

This rate is similar to the above. Vehicle kilometres are a better measure of transport demand than vehicles numbers, but are much harder to estimate. Therefore this rate is relatively seldom used.

3.2 Microscopic Scale

In order to assess the risk on a short stretch of road, or at a curve or intersection or some other road feature, a rate is normally used which utilises whatever exposure to risk information is available. Thus the rate used at a crossroad may be accidents over a time period divided by the product of traffic flows on the two legs. At a bend it might be accidents divided by traffic flow. On a stretch of road it may be accidents divided by vehicle kilometres on the stretch.

3.3 What Do These Accident Rates Mean?

As is obvious, these rates are not in fact probabilities of having an accident. Rather, they are ways of comparing relative risk as a basis for further action.

4. Available Risk Data

To compute the above rates one needs both the numerators and denominators. The Ministry of Transport collects data on reported accidents involving injury, and on some non-injury accidents. It is estimated that information on about 50 percent of all injury accidents becomes included in the Ministry's database. Injury data, which may be used in a similar way to accident data, is available from ambulance, hospital and Accident Compensation Corporation (ACC) sources. Vehicle data is available from New Zealand Post. Traffic counts and road lengths are available from Transit New Zealand for state highways, and from local authorities for some other roads. The Ministry of Transport also carried out household-based travel surveys in 1976 and 1989-90, with the objective of assessing exposure to road accident risk to various groups in the community.

5. Risk Perception

Decision-making in road safety leans heavily on cost–benefit analysis, the major tool used in ranking projects. Safety projects have to compete with other projects where the savings might be in, say, travel time rather than in damage or injury. Thus accident cost values are crucial in setting priorities. These values are set by a 'willingness to pay' approach. The present values originate from a household survey which asked householders what they were willing to pay to reduce their road travel risk by a finite amount (Millar and Guria, 1991). This resulted in a value for death avoidance of $2 million. Values for injury avoidance have been produced (Guria, 1991) and are being further refined. These use estimates from injury cost and property damage cost data, except for costs of pain, grief and suffering, and permanent disability. In these cases the values are estimated as proportions of the willingness to pay to avoid death. Thus, in road safety, perceived risk as manifested in people's willingness to pay to avoid risk plays an intrinsic role in decision-making.

6. Risk Criteria

6.1 Laws and Regulations

Road safety is generally governed by the Transport Act 1962 and its regulations pertaining to the behaviours of traffic and vehicle operators, and the construction of vehicles. The process by which road safety projects are ranked alongside other projects is set out in the Transit New Zealand Act 1989.

6.2 Standards and Codes of Practice

Both the Land Transport Division of the Ministry of Transport and Transit NZ have standards-setting roles regarding safety. The Land Transport Division's area is movement on roads, devices to assist that movement, vehicles and vehicle operators.

Transit NZ's area is the design of the hard infrastructure of the road. There is some overlap of responsibilities which is dealt with by negotiation and co-operation using such solutions as the production of joint standards. Some of the standards set are mandatory, such as the standards for traffic signals, motorcycle crash helmets, seatbelts and overdimensional loads. Other standards or codes of practice, such as those for hazardous goods movement, security of loads and school patrol operation, are voluntary. However, any of these could be made compulsory were they to be heavily flouted.

6.3 Safety Audit

The Land Transport Division is at present moving, wherever possible, towards a safety audit approach to road safety service providers that will require providers to set up their own internal quality control mechanisms which will be subject to audit by the Division. This is already happening with warrant-of-fitness testing and has the potential to be extended to such areas as vehicle fleet operation, driver testing and the provision of traffic enforcement. Transit NZ is attempting to set up a similar approach for its internal operation.

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SEISMIC HAZARD AND RISK ASSESSMENT

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1. Introduction

While ground shaking poses the commonest seismic hazard, earthquakes may also cause a variety of other geological and consequential hazards, for which a checklist should include:

- Ground shaking
- Fault displacement
- Subsidence (flooding and differential settlement)
- Liquefaction of cohesionless soils
- Failure of sensitive or quick clays
- Landslides
- Mudflows
- Dam failures
- Water waves (tsunamis, seiches)
- Groundwater discharge changes
- Fires

In many seismic risk assessments some of the phenomena on this list may in fact be likely to occur, but in practice may not be considered. The reasons for not considering them range from ignorance to judgement, and may or may not be justified in an objective sense.

This paper discusses only the most important factor, that is, ground shaking.

2. Definitions of Hazard and Risk

As discussed in a briefing paper for this workshop[1], the usage of terminology within the general subject of risk is confused. Gardenier's preferred definitions of the terms *hazard* and *risk* may be usefully compared with those recommended in the USA by the Earthquake Engineering Research Institute's Committee on Seismic Risk [2], which are widely (but not universally) used by professionals involved with earthquake risk. The two sets of definitions are given in Table 1.

Table 1 - DEFINITIONS OF 'RISK' AND 'HAZARD'

	Definitions	
Terms	**Gardenier [Ref 1]**	**EERI [Ref 2]**
RISK	"The probability of a specified loss or harm" specified values at a site, at several sites, or in an area, during a specified exposure time."	"The probability that social or economic consequences of earthquakes will equal or exceed Risk has a consequence component and a probability component.
HAZARD	"The potential loss that can cause human, social, environmental or economic harm." human activities." Hazard normally refers to the magnitude of the loss or harm. It is the consequence component of a risk.	"A physical phenomenon (e.g. ground shaking, ground failure) associated with an earthquake that may produce adverse effects on Hazards may be purely descriptive terms or quantitatively evaluated.

The two definitions of ***risk*** in Table 1 are obviously the same, and the definitions of ***hazard*** are the same if Gardenier's word 'loss' is equivalent to 'physical phenomenon'. However, it is not clear whether the Gardenier definition of *hazard* conforms with the widely used expression for *risk*, which says that it is an outcome of hazard as described by the relationship:

$$\text{Risk} = (\text{Hazard}) * (\text{Vulnerability}) * (\text{Value}) \qquad (1)$$

where ***vulnerability*** is the amount of damage induced by a given degree of hazard, expressed as a fraction of the *value* of the damaged item under consideration.

In New Zealand in recent years (see, for example, Refs. [3,4]), the term ***seismic hazard*** has often been used to mean "the strength of ground shaking at any given site of a given probability of occurrence". This usage seems to conform with the requirements of equation (1) and the EERI definition of the term.

3. Quantification of Seismic Hazard and Risk

3.1 Methodology

The principal steps involved in quantifying seismic risk due to ground shaking concern the evaluation of the following:

(1) *Earthquake sources* affecting site(s) concerned

(2) *Attentuation* of shaking between source(s) and site(s)

(3) *Effects* (responses) at site(s) and their *probabilities* of occurrence in a given time interval.

Earthquake sources are descriptions of future activity in terms of size, time (frequency) and location. *Size* is described as magnitude; *frequency* is some kind of irregular time-series; and *location* may be described as sources which are uniformly distributed over a geographical area, or may be confined to specified line sources (fault lines) or fault planes. For areal sources, activity is generally described in the form:-

$$\begin{aligned} \log N &= A - bM, \qquad M < M_{max} \\ N &= O, \qquad M > Mmax \end{aligned} \tag{2}$$

where N is the number of earthquakes of magnitude exceeding M occurring in a given area (usually 1000 km²) per year, and constants A and B vary from region to region.

Attenuation describes the rate of decay of an effect i with distance r from source and as a function of magnitude m, so that in general

$$i = i(m,r) \tag{3}$$

which may be inverted to give the magnitude necessary to just product effect i at a distance r. That is:

$$m = m(i,r) \tag{4}$$

More specifically, attenuation of i may be expressed in the form

$$\log i = b_1 + b_2 M + b_3 r + b_4 \log r \tag{5}$$

where b_1 and b_4 are empirically derived constants.

In equation (5) i is usually a physical response such as an acceleration or velocity, or log i may be replaced by a felt intensity (Modified Mercalli). This equation has a probability distribution associated with it.

Combining the above source and attentuation models leads to the probability p_i that any earthquake occurring at random in the source region will produce an effect with strength exceeding i at the site:

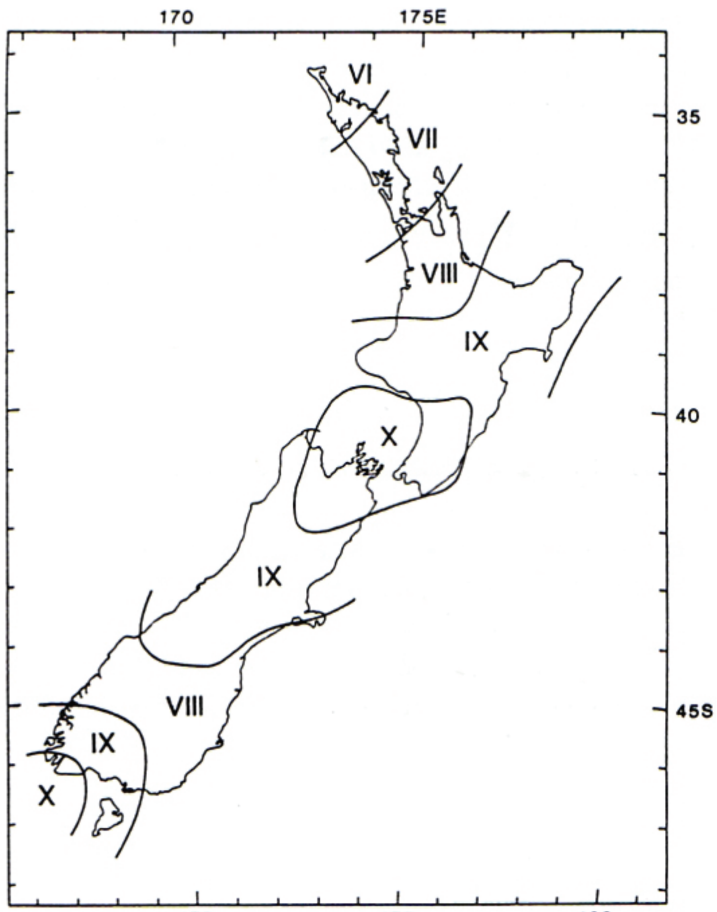
$$_{p}i = P[I > i] = \int_R \int_M P(I > i \setminus m,r) 10^{-bm(i,r)} f_a(r) dm\, dr \tag{6}$$

where $f_R(r)$ is the probability density function of distance r, and has simple algebraic forms for areal or linear sources.

Such seismic hazard estimates have been mapped for regional variation in New Zealand for Modified Mercally Intensity [3] and for one specific acceleration effect [4], as illustrated in Figure 1.

Figure 1 - INTENSITIES WITH A 5% PROBABILITY OF OCCURRENCE WITHIN 50 YEARS

(after Ref. 3)



The *Effects i* at a site, as described above, take account of the source and travel path (attenuation), but in general are also subject to modification at the site due to local geological conditions (sometimes called *ground classes*). In 1985 a first attempt was made to assess New Zealand ground class effects [4], and this was done in terms of four broad ground classes. More recently, work has started on mapping local differences in ground conditions in *microzoning* studies of major urban areas: that is, Wellington, the Hutt Valley [5] and Christchurch. Detailed studies of specific sites are routinely carried out for important projects , for example the Maui B Platform and the Museum of NZ project.

Finally, the effect *i* at the site has to be transferred to those items at the site for which we wish to assess the response to an earthquake. Such items, of course, are many and varied and include, for example:

- earth dam
- unstable hill slope
- house chimney
- ground floor column in a building
- computer on 17th floor of a building
- printing press in a building
- capacitor bank in electricity sub-station
- converter in petrochemical plant
- person in a tunnel or in a crane

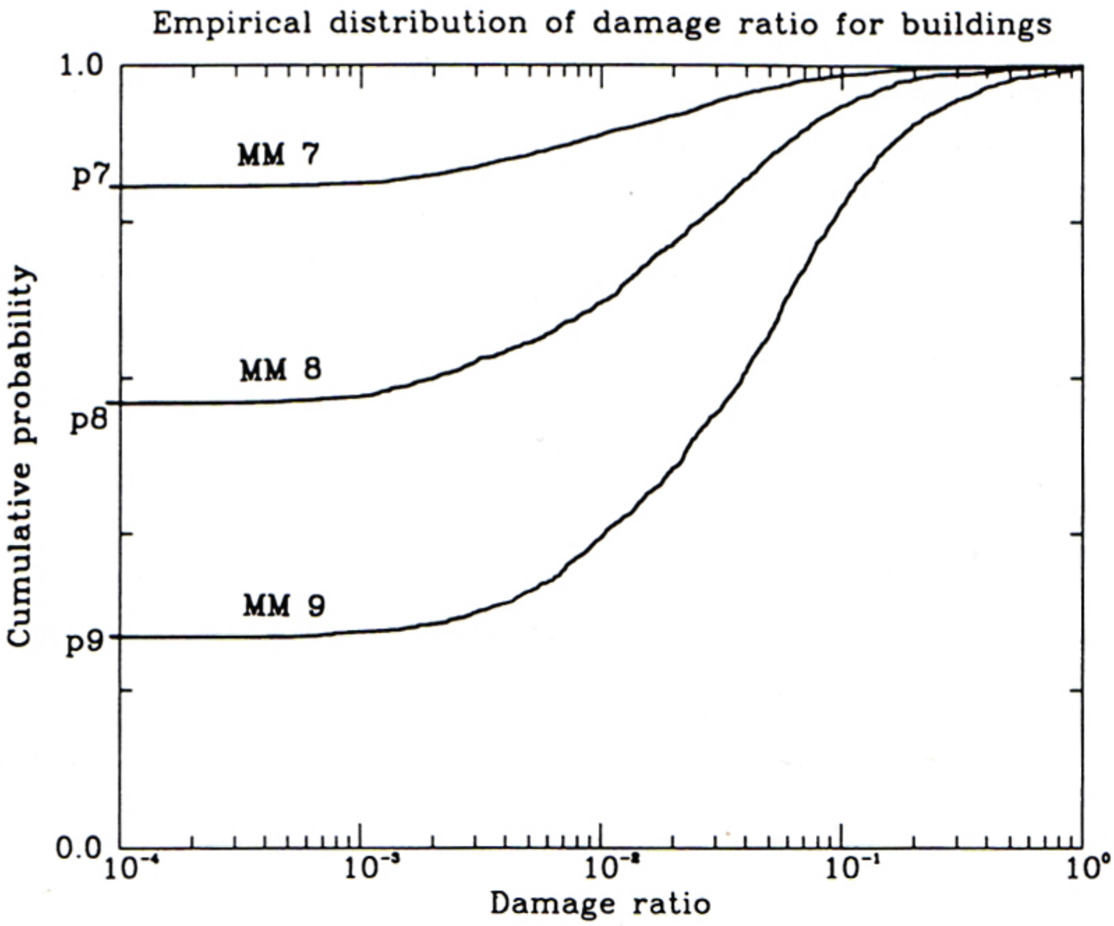
Therefore, the *microzones* site effect finally has to be modified by an analysis of the building or equipment item to find the responses (effects) of the items under consideration. These desired response estimates are of two types:

(i) design criteria (stresses, displacements)

(ii) damage forecasts (to buildings, equipment, dams, landscape, people)

Design criteria are determined by a structural analysis. ***Damage estimates*** may also be made in this way, but are more commonly derived from damage ratios (=Vulnerability in eq. (1)) for given classes of items, which are a function of the intensity at the site. The probability distributions of damage ratios have been described for New Zealand houses (Figure 2) and household contents in a recent study of the 1987 Edgecumbe earthquake [6,7], and similar data will soon be available for commercial/industrial property from ongoing studies by this author.

Figure 2 - EMPIRICAL DISTRIBUTION OF DAMAGE RATIOS FOR HOUSE BUILDINGS (INCLUDING UNDAMAGED HOUSES) FOR THREE INTENSITY ZONES OF THE 1987 EDGECUMBE EARTHQUAKE (after Refs. 6,7)



Damage cost estimates for potential future earthquakes are routinely made for insurance or financial planning purposes, for individual items of property or groups thereof. An example of the latter is the recent study [8] of losses that might be incurred in large earthquakes by the Earthquake and War Damage Commission which at present underwrites the indemnity value of most buildings and their contents/equipment throughout New Zealand.

3.2 Data Sources

There are various sources of seismic hazard-related data in New Zealand, as described broadly in Table 2.

Table 2 - SEISMIC HAZARD DATA SOURCES

Data Type	Collection Point		Sources
Seismicity	Public	NZ Seismological Observatory (DSIR)	Annual Reports; papers; databases
Strong ground motion	Public	DSIR Physical Sciences University of Canterbury (small)	Reports; papers; databases
Geological/techtonic earthquake sources	Public Private	DSIR Geology & Geophysics Universities Oil/mining companies Consultants	Papers; databases
Attenuation	Public Private	DSIR Consultants	Reports; papers Databases
Local site geology, Microzoning	Public Private	DSIR Local authorities (some only) Property owners Consultants	Reports; papers Databases
Response Analysis	Public Private	Universities DSIR Local authorities Consultants, contractors Commercial/Industrial companies State-owned enterprises	Reports; papers Computer programs
Damage Costs	Public Private	Local authorities Government departments Earthquake & War Damage Commission Insurance companies Private property owners State-owned enterprises	Reports; papers Databases
Damage Ratios	Public Private	DSIR Physical Sciences Insurance industry	Reports; papers

Improving the accessibility of data is a subject of varying complexity, depending on the type of data. In general, data held in the private sector is not available to other parties, therefore some means of obtaining important parts of that data is desirable.

3.3 Methods of Obtaining Initial Estimates of Seismic Hazard

The best way of doing this is to consult someone with considerable knowledge and experience in the subject. Preliminary data is best obtained from Refs. 3 and 4, but these need interpretation by people of appropriate background.

3.4 Community Risk — Use of Risk Maps

The method for assessing seismic risk, as outlined earlier, treats individual or multiple sites as required. Nationwide hazard maps [3,4] have been in use for some time.

Microzoning maps to differentiate seismic hazard within a given area are now beginning to be produced (for example, Ref. 5). This is a very difficult task and such maps will remain in a research phase for some years to come, but they have the potential to become very significant planning/designing tools.

4. Risk Perception

In New Zealand to date decision-making on seismic risk issues seems (to the author's knowledge) to have been left largely to the specialists, especially in the formulating of regulatory documents. Lay people are more concerned with individual decisions: that is, whether specific construction projects should go ahead, or how much earthquake insurance should be bought for a particular property. In those cases, lay opinion may be either more or less pessimistic than those of the specialists.

5. Seismic Risk Criteria

There are many criteria for seismic risk due to ground shaking. These relate to the protection of people and/or property and may be found in national standards, codes of practice, local authority bylaws, recommendations of various organisations (for example, professional societies, industrial associations, universities, research associations and large corporations), and reports, books and papers by individuals.

Even a representative list of such publications would be very long, so instead I will restrict myself to listing a few of the more important New Zealand documents, as follows:

(i) NZS4203:1984 *Code of practice for general structural design and design loadings for buildings.*

(ii) NZS3101:1982 *Code of practice for the design of concrete structures*.

(iii) NZS3603:1990 *Code of practice for timber design*.

(iv) NZS4230:1990 *Code of practice for the design of masonry structures.*

(v) NZS3404:1989 *Code of practice for Steel Structures* "New Zealand amendments to AS1250".

(vi) NZS4219:1983 *Specification for seismic resistance of engineering systems in buildings*.

(vii) NZ National Society for Earthquake Engineering (1985) *Recommendations and guidelines for classifying, interim securing and strengthening earthquake risk buildings*.

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RISK ASSESSMENT IN CIVIL ENGINEERING

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1. Overview

Civil Engineering contains many subdisciplines which tend to have different needs and approaches to risk management. The major traditional areas are structural engineering, hydraulics, geotechnical engineering, transportation, public health/ environmental engineering, and perhaps, because the study of risk is integrative, lifeline engineering. Before looking at them in detail, a few preliminary comments must be made.

1.1 Often, because natural hazards are involved and major events (volcanic eruptions, for instance) are infrequent and have complex effects, the data available for formal quantitative risk assessment are sparse and unreliable. This raises serious questions as to the limits of applicability of formal risk quantification procedures.

1.2 It follows that there must be doubts as to the possibility of setting formal quantified risk standards for all situations which is the principal reason why there are few published quantitative risk standards in civil engineering of the sort that might be seen in, say, chemical engineering.

1.3 It may be more appropriate in some situations to require a formal risk assurance procedure, analogous to quality assurance, rather than the meeting of a standard.

1.4 Where data is poor, *comparative* risk assessments are more reliable than attempts at absolute risk assessment. However, it could be said that, ultimately, all risk assessments are comparative in some sense.

1.5 Two points that must be kept in mind in dealing with risk assessment are that risk is always associated with a decision of some sort, and that risk assessment should usually be part of a risk management process.

1.6 Historically, most risk assessment work in civil engineering has focused on the probability of some event happening — the collapse of a structure, for instance — rather than on quantified loss of life or injury. Loss of life has been dealt with implicitly through code provisions.

2. Structural Engineering

We shall consider the structures dealt with in four categories: buildings, bridges, dams, and other major structures.

2.1 The risk management of buildings has been carried out almost exclusively through the use of codes of practice. Nowadays, structural building codes are based on risk assessment procedures. The codes are generally prescriptive, in effect specifying the safety factors a designer must use. Performance-based codes are not normally used. There are exceptions: the Scandinavian code was performance-based in that it overtly required various safety levels to be met (related to probabilities of structural failure). However, designers could not afford to use such codes in practice as they could not afford to carry out a risk assessment on each building they worked on.

Building codes are explicitly concerned with structural failure. Implicitly, they deal primarily with loss of life, though with some consideration being given to prevention of property loss. They pay attention to societal risk as well as individual risk by requiring more stringent standards for buildings containing many people, such as places of assembly.

The levels of individual and societal risk implied by New Zealand's building codes havenever been assessed. To do so would be an important and useful exercise. Nevertheless, despite the sophistication of the risk analyses behind building codes, in some areas the models on which these analyses are based are far from satisfactory. For example, one result of this is that it is impossible to say whether the implied risk levels for, say, earthquakes bear any relation to those for wind loads.

Another lack is that there has been no systematic study of the risks to buildings posed by vulcanism, although the historic loss of life due to volcanoes is of the same order of magnitude as that due to earthquakes.

Risks due to fire in buildings are also dealt with through the use of prescriptive codes of practice. Such codes are not normally based on formal risk assessments and are not therefore as sophisticated as the structural codes related to natural hazards. Work has been done (Buchanan, Platt and Elms 1989) on a general fire risk analysis for multi-compartment buildings which deals explicitly with both life and property loss. However, its use is restricted to comparative analysis rather than absolute, as it uses a relatively simple model of the process of fire spread.

Nevertheless, it is of interest because it seeks to overcome a significant limitation of conventional fault-tree and event-tree analyses by taking into account the time taken for different fire-spread events to occur.

2.2 Risks associated with the failure of a bridge are not primarily those of loss of life, even though people may die in a bridge failure. Economic and social losses are more important, as illustrated by the results of the collapse of the Tasman Bridge in Hobart due to ship collision. Until recently, however, engineers would not even do the most elementary of risk assessments on bridges. A quite simple assessment of the risk of ship collision, for instance, could have prevented both the Tasman Bridge disaster and the greater financial disaster of the Chesapeake Bay Bridge Tunnel in America.

In New Zealand primary causes of bridge failure are earthquakes (dealt with by a code of practice) and scour. Risk assessments now being carried out, or proposed, to take into account the significance of the route of which the bridge is a part.

2.3 Nowadays no dam could be built without a risk assessment related to the consequences of failure. Yet, worldwide, dam failures have been a major source of loss of life. In the US, a presidential memorandum about 15 years ago required the safety assessment of all significant existing dams (Lave *et al.*, 1990). There is no clear standard of acceptable risk. However, if the disaster potential of a dam is too high it should not be built, as with a dam proposed upstream from Sacramento, California, whose failure in an earthquake could lead to an estimated 130,000 deaths (Pate-Cornell and Tagaras, 1987).

2.4 There are many other major potentially hazardous structures besides buildings, dams and bridges: storage tanks, silos and towers, for instance. However, by far the greatest effort has gone into the risk assessment of reactor containment vessels and other structures for the nuclear industry potentially subject to natural and other hazards. These would not normally be full assessments on their own, but would be part of a larger exercise, feeding in information on probability of structure failure to an overall risk analysis.

3. Hydraulics

Areas of risk dealt with in the general disciplines of hydraulics, fluid mechanics and hydrology are, among others, the effects of dam failure, flood plain risk, coastal damage, and general environmental problems such as the risks of ocean outfall and thermal pollution.

In none of these areas are there quantified risk targets expressed in terms of loss of life. Two obvious areas where quantified risk targets could be useful are dam failure and flood plain management. As the others tend to result in property and environmental damage, life-loss standards are inappropriate.

Where the hazards involved relate to economic damage, a sensible strategy is to use a risk balancing approach which seeks the best way of investing a fixed sum to minimise total cost.

4. Transportation

The different areas of transportation tend to be specialist areas with little overlap. The four major categories are: air, road and rail transportation, and shipping. Civil engineering involvement in air transport and shipping is normally limited to ground and port facilities so these areas will not be considered further.

4.1 Risk reduction strategies have always played a major part in rail operations, although formal risk studies have carried out only recently. Historically, rail risk management developed in two major phases: first, strategies were developed to make sure accidents did not happen, and then effort was put into ensuring that the consequences of accidents were minimised. Emphasis was primarily on safety rather than economic loss, and possible environmental consequences were not considered at all. The probability of accidents was minimised by the development of sophisticated signalling systems and by the introduction of codes of procedure in the form of rule books. Consequence control was achieved by appropriate design of rolling stock so that carriages were less likely to be crushed or to burn.

Rail transport is generally very safe. Locomotive engineers in New Zealand have in FAR when driving of about 13 (Elms and Mander, 1990). However, the public is very averse to a major disaster such as the Clapham Junction collision in 1988, discussed in the Hidden Report (Hidden, 1989).

However, data is sparse, so that formal quantitative risk assessments cannot easily be carried out, except in a comparative sense or in a very specific situation or location. Qualitative risk assessments are often more appropriate, and NZ Rail has commissioned some useful (unpublished) studies.

More important than risk assessment is the need to control risk by setting up formal and thorough risk management procedures — a necessary approach for any operation in which failure occurs more as a result of human error than for physical reasons.

4.2 In the area of road transport it is much easier to obtain risk values, in the sense of accident data, because there are many fatal accidents. Dollar values are put on lives lost in order to help decide the levels at which to invest in safety measures and accident prevention.

Until recently in New Zealand, a rough guideline for intervention was five accidents in five years for a specific site, and five accidents per 0.5 kilometres in a length of road (National Roads Board, 1986). Now, however, Transit New Zealand provides no guidelines at all on the grounds that they can be misleading in some cases and might inhibit an otherwise deserved intervention.

For the purposes of the economic evaluation of projects, the value of a human life was until recently set at $235,000. In May 1991, however, the Minister of Transport announced a new figure of $2 million (Automobile Association, 1991).

5. Public Health/Environment

Civil engineers have traditionally had a leading role in the provision of a healthy environment. They have been concerned with providing good drinking water, sewage disposal and solid waste disposal. It is now recognised that some earlier efforts at waste disposal were wrongly directed, leading now to massive efforts in the United States and in other countries to deal with groundwater pollution and solid waste problems such as the notorious Love Canal.

Where risks can be quantified in terms of loss of life, the figures given earlier by John Gardenier are generally applicable. However, most authorities have not wished to adopt the societal risk curves used in the Netherlands because there is general unease about their use. Two specific criticisms are that there is too great a distance between their bounding lines, and that they cannot deal with a project whose computed S-N curve crosses a bounding line.

However, in most cases of environmental risk assessment, human mortality cannot be used as a measure or risk. It is often difficult to determine what measure should be used. In most cases, different effects must somehow be compared together in the same assessment. There are various techniques for doing this, but in many instances the most sensible approach is to do a qualitative rather than a quantitative risk assessment.

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RISK QUANTIFICATION IN THE INSURANCE INDUSTRY

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1. Introduction

M&M Protection Consultants (M&MPC) is a division of Marsh & McLennan Ltd, a New Zealand registered wholly-owned subsidiary of Marsh & McLennan Companies of New York.

Marsh & McLennan Ltd are international risk management consultants and insurance brokers with a total of about 140 staff in New Zealand. The company was first established here in 1963 and head office is in Auckland.

M&MPC is concerned with the correct identification of risks, and with the control and mitigation of hazards. There is an international M&MPC resource with which the New Zealand division interacts. With a total international staff of about 300, M&MPC deals with a very broad range of industrial, commercial and institutional risks.

In order to discuss risk quantification with particular emphasis on insurance, the basics of insurance should first be considered.

2. Insurance Basics

2.1 The Policy

An ***insurance policy*** is a contract to make good (financially indemnify) should loss occur. The premium is the consideration and is usually computed as a (premium) rate x sum insured. Insurance contracts are deemed to have been entered into on the basis of '*luberimae fide*' which means that both parties must disclose material facts.

2.2 Purpose

Insurance is a financial device to fund losses. The costs of a loss are spread over time or over 'the many'. Insurance is only needed if the *maximum probable loss* is greater than the owner's ability to comfortably directly fund the loss. It thus provides a means to enable the owner to fulfil their post-loss objectives and obligations.

2.3 Methodology

The insurer must ensure they are able to fulfil the contract in the event of a loss — that is, fund the loss and preferably, from their point of view, also make a profit.

The two main techniques used by insurers are:

- ***underwriting*** – that is, evaluating and understanding the risk and ensuring a reasonable spread of risk (geographically, class of business, and so forth).
- ***reinsuring*** or ***'laying off'*** – that is, reinsuring with other insurers (either by a standing treaty arrangement or by one-off facultative agreements).

Insurance companies, historically, are organised into various market risk sectors: marine, property, liability and casualty. These are further split into subsections such as construction, aviation, oil and gas, and professional indemnity.

2.4 Insurers' Approach to Risk

Insurance companies are in the business of insuring, and in doing so must be profitable. The profit a company makes is the difference between the premium and reinsurance costs, administration costs, brokerage and claims, plus any investment income it receives.

The main variables are reinsurance costs and directly funded claims. When interest rates are high, premiums usually decrease if there is excess market capacity.

In evaluating an insurance proposal the insurer must consider:

- **reinsurance costs**:
  - what is the maximum probable loss (MPL)
  - insurer's underwriting 'house rules'
  - class of business spread
  - dependencies

and

- **likely claims:**
  - past experience (a material fact)
  - expected frequency and severity of non-reinsured portion or risk (judgement)
  - deductible levels, that is the lower threshold at which the policy will begin to meet the costs of a loss (these may be expressed in dollar terms or in time in respect of consequential loss).

2.5 Risk Evaluation

In the insurance industry risk can be defined simply as the possibility of an adverse deviation from goals. This 'adverse deviation' is normally associated with additional costs.

Evaluation techniques used in assessing the risks associated with a proposal vary depending on the industry sector, capital value, and the value of the product and processes involved.

In general, evaluation is aimed at determining the *maximum probable loss* (MPL), the worst loss that could be expected if all protection procedures fail; and the *normal loss expectancy* (NLE), the worst loss expected if all protection systems are operational. The MPL influences the reinsurance requirement, while the NLE influences the claims component of the premium.

In order to arrive at the MPL and NLE it is necessary to attempt to qualitatively (or quantitatively, if feasible and necessary) assess the severity of events that are likely to result in a loss or in an adverse deviation from goals.

Additionally, the probability/possibility of such loss events must be estimated. Insurers are interested in both the frequency and severity associated with a particular risk. Typically, this is achieved through review of loss experience and comparison of risk control activities against notional industry norms.

In preventing risk to insurers it is important to present the risk thoroughly and fairly. Uncertainty breeds fear and hence higher insurance rates. The following information must be assessed and presented in an insurance risk evaluation in the process industry:

- location
- infrastructure
- access
- topography
- natural hazards
- layout (separating)
- construction (design hazard control)
- process flows
- utilities
- dependences
- plant and machinery reliability
- protection systems/features installed
- management control systems (hazards, maintenance, training, contingency planning)
- waste disposal
- customer dependences
- history of loss experience
- plant values
- loss estimates

2.6 Risk Assessment Techniques Used

There are numerous risk assessment techniques available to the insurance industry, as this workshop has demonstrated. Many of the techniques discussed are used when assessing insurance proposals.

- gut feel (experience, judgement)
- qualitative risk evaluation (ranking)
- quantitative risk evaluation (high risk process industries)
- reliability studies (machinery)
- HAZOP (new plant and expansions)
- toxicity (environmental)

It must be stressed, however, that use of technical risk assessment techniques should not overshadow the importance of evaluating the human element aspects of a facility. Standards for the application of management control systems cannot be over-emphasised, as has been demonstrated in many catastrophic events.

A LOCAL GOVERNMENT VIEWPOINT ON RISK ASSESSMENT

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Almost all the activities of local government involve risk to some degree, and functions spanning a wide range of disciplines each bring their own specialist approach to risk management — although many of these disciplines overlap.

A local authority is, however, in the unique position of being responsible for the public goods and services of a local community. It is therefore often the interface between projects or works and those affected by the consequences of those works.

When a disaster occurs as a consequence of a hazard the question of negligence arises and, invariably, the Local Authority is, by its very nature, one of the parties available to be targeted for litigation. Many of the other parties may well have disappeared from the scene. It is therefore very important that both local government and the public have an understanding of risk .

Typical types of hazards or risks that are dealt with or should be dealt with in local government include:

a) **Subdivision of land**
Erosion, subsidence, inundation or other flooding.

b) **Building regulation**
Structural integrity, health, fire prevention and egress.

c) **Planning**
Avoidance and mitigation of hazards including earthquake, geothermal and volcanic activity, flooding, erosion, landslip, subsidence, silting and wind.

d) **Civil Defence**
Planning for and responding to the consequences of an event.

e) **Community services such as drainage, water supply and transportation**
Risk from lack of continuity of service, or risk to the integrity and safety of these systems as a result of hazards (including hazardous substances).

f) **Community health**

g) **Financial and economic areas**

h) **Waste disposal**

In general, the concepts of risk are poorly understood both by the public and by local authorities.

While publications such as the Institution of Professional Engineers New Zealand's *Engineering Risk* has assisted in promoting understanding of risk, further work is required. A ready example of lack of understanding about risk is the area of flood risk where the frequency of events is not clearly understood as a measure of risk.

Public understanding of risk is often limited to short-term recent experiences.

The transient nature of New Zealand's population often limits the extent to which expertise is available.

Understanding of risk is generally traded off against pressure on local authorities to either ignore or allow risk to be accepted in return for profit or financial gain.

A decade of rapid legislative change has resulted in local authorities often reallocating responsibility for the consequences of risk without this necessarily being understood. At the present time, legislation such as the Building Bill, or the use of the Local Government Act for the corporatisation of Trading Enterprises, involve a shift in responsibility for risk that is not widely understood.

The problems alluded to above will be assisted by tools that standardise the quantification of risk, and hence its perception.

Risks inherent in local government range from policies responding to large natural disasters to the cumulative effects of isolated black-spot accident sites on roadways.

The increasing trend to pursue local government for claims of negligence in the event of accidents or disasters emphasises the need to recognise hazards when planning. Local government is recognising that it is invariably one of the parties remaining to face litigation, and if not cited as first defendant then it is highly likely to appear as second or third defendant.

A dimension which needs to be recognised in the urban situation is the size of a hazard in terms of the ability to cope with its consequences when large numbers of people are involved. When managing risk, recognition needs to be given to scale.

Only recently have local authorities tended to involve the public in assessing what levels of risk may be acceptable to the community when determining design parameters for such things as stormwater systems.

RISK COMPARISONS AS AN APPROACH TO ASSESSING ENVIRONMENTAL RISK

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1. Introduction

In this brief paper I present a definition of environmental risk and make some comparisons with other forms of risk. I then describe approaches to qualitative and quantitative risk assessment, with emphasis on applicability to environmental risk assessment, and continue by examining some of the special problems introduced by the nature of environmental risk.

A recent United States approach to evaluating priorities for action on environmental risk issues involves an adaptation of the *risk comparison* technique. I refer to one application of this technique and conclude with a brief discussion of the possibilities of applying this approach in the New Zealand context.

2. What is Environmental Risk?

I would like to begin by defining ***risk*** as *the probability that a particular adverse event occurs times the magnitude of the expected harm or loss associated with that adverse event*. Risk is always associated with a *choice of action*. In cases of involuntary risk the persons likely to be affected or those who *bear* the risk are different from those who make the decisions or *take* the risk. Therefore, risk decisions involve equity issues.

In the context of this paper ***environmental risk*** refers to all risk to the environment resulting from human activity The 'environment' is not restricted to the natural environment, but also encompasses the social environment. Therefore, another way of describing environmental risk is risk to the natural environment or ecological risk, risk to human health and risk to lifestyle or *the things we value*.

Other types of risk include engineering risk, financial risk, business risk, political risk and institutional risk. The definition of risk given at the beginning of this section is not held consistently over all disciplines. Some groups use the term 'risk' as meaning simply the ***probability*** of the occurrence of an adverse event. These differences are not important as long as they are generally understood. Also, in the case of business risk and financial risk, the outcomes are likely to represent *gain* rather than *loss*: that is, the outcomes may be positive rather than negative.

The differences between types of risk are associated with the *outcomes*. The concepts and procedures used are similarly derived, and most methods of risk assessment are applicable across different types of risk.

3. Quantitative and Qualitative Risk Assessment Procedures

Risk assessment is the general term used to describe the study of decisions subject to uncertain consequences (Royal Society, 1983). It is divided into: ***risk estimation,*** which involves identification of the outcomes, estimation of the magnitude of the associated consequences of these outcomes and estimation of the probabilities of these outcomes; and ***risk evaluation***, the process of determining the significance of value of the identified hazards.

Risk management involves the process of decision-making, followed by the implementation and monitoring of that decision.

Risk assessment can be divided into two broad categories: quantitative and qualitative risk assessment. Quantitative techniques attempt to objectively define and quantify risks. Qualitative techniques take a more subjective approach and acknowledge that value judgements are an integral part of the risk assessment process. They are also used when there is less quantitative data available. In reality, both techniques contain subjective elements because quantitative risk estimates are based on the selection of certain assumptions (Pyle and Gough, 1991).

Quantitative risk assessment (QRA) is sometimes also referred to as technical risk assessment. QRA relies heavily on numerical analysis and availability of numerical data. There are four main categories of technical assessment:

(1) statistical analysis of past events with similar consequences to that being studied;

(2) extrapolation techniques using past occurrences of less severe events as a basis;

(3) event tree analysis, most commonly used when a hazardous occurrence has many possible causes and when no suitable past information is available; and,

(4) fault tree analysis, which is similar to event tree analysis except that it begins by considering an undesired outcome and then develops all possible routes to that event (event tree analysis works from cause to effect).

Qualitative methods can allow for a greater range of risks to be included in the risk assessment process because they are not so reliant on numerical data. The three main types of qualitative risk assessment technique are:

(1) the decision-analytic approach, which involves an extension of technical assessment into areas of subjectivity;

(2) the risk perception approach; and,

(3) the policy-analytic approach, which can be used to devise a framework incorporating a number of risk assessment techniques.

Recent developments include a process known as the 'precautionary approach' which adopts a conservative attitude towards environmental risk (the environment is given the benefit of the doubt). It derives from risk perception approaches and attempts to take more specific account of the many uncertainties involved in environmental risk.

There is no 'right' way of assessing risk. Quantitative and qualitative processes both have their own particular place and neither one is better than the other in all situations. In most cases, some combination of techniques is most appropriate. Because of the many different types of hazards which may be involved, particularly in environmental risk situations, generalised or 'cookbook' processes are not appropriate, and it is important to consider each situation according to its own character and requirements.

It should also be remembered that we cannot eliminate risk. What we can do is seek to *manage* or *reduce* risk by making good decisions, which requires careful systematic evaluation and consideration of the value structures of the communities involved (both those benefiting and those 'losing' or bearing the risk).

4. Some Special Problems Associated with Risk Assessment of Environmental Hazard

There are a number of limitations to the risk assessment process which have specific relevance when we are considering environmental risk.

Firstly, environmental risk situations are characterised by lack of data and considerable uncertainty. Environmental risk situations tend to have much longer time horizons than technical risk situations. In many cases, it is necessary to take into account the interests of future generations when assessing environmental risk. Despite considerable advances being made in the area of non-market valuations (Kerr and Sharp, 1987), it is extremely difficult and probably foolhardy to try to quantify the value of a current resource to future generations. What we do need to do is to avoid *irreversible* impacts such as destruction of species or ill-considered depletion of a resource.

A second limitation of risk assessment for environmental hazard is associated with the *quality* of the data. Of necessity, many assumptions will be made which may have considerable effect on the results of the procedure used. For this reason, risk assessment is most appropriately applied as a *comparative* tool where several possible options are estimated and compared in order to select a 'best' option.

Finally, environmental risk decisions tend to be *political* decisions: that is, environmental risk issues require recourse to the public sector decision-making process. Therefore, additional problems are faced, such as the need to communicate technical information in such a way that it can be understood and *accepted* both by members of the public and by members of the decision-making body.

5. Environmental Risk Priorities

Modern society is beginning to recognise and be concerned about an increasing number of areas of significant environmental risk. Many of the problems encountered arise from previous indiscriminate use of unsuitable sites for waste disposal, such as occurred at the Love Canal site in the United States. These types of problems are not necessarily the result of careless or deliberate indiscriminate dumping, but may be due to ignorance about the direct potential health and environmental effects, ignorance about the effects of mixing certain waste types, and ignorance about the long-term effects of containment. Other areas of concern are arising as scientific and medical knowledge increases and unthought-of health risks are identified (for example, radon in houses, and low-level electro-magnetic radiation).

At the same time, agencies such as the United States Environmental Protection Agency (USEPA), which are charged with the responsibility for environmental protection, are finding that the originally apparently abundant economic resources (such as the Superfund) allocated to them are inadequate to deal with all the problems and issues which are put to them. In the past, the USEPA has paid less attention to natural ecosystems than to human health because ecological degradation was seen as a less serious problem, partly because of its perceived lack of immediacy. However, the cost of not understanding or taking into proper account the value of natural ecosystems is now recognised as being potentially disastrous in terms of loss of productivity, loss of species and eventual carry-over effects on human health. This situation is not unique to the United States. At the present time Germany is also undertaking a massive stocktaking of waste sites preparatory to determining priorities for action (Fulgraff, 1990).

The question therefore becomes: how do agencies charged with responsibility for environmental protection allocate their resources? In 1987 the USEPA produced a report entitled *Unfinished Business*, which comprised a comparative assessment of environmental problems. This report was recently reviewed by the Science Advisory Board of the USEPA for the purpose of recommending strategies for reducing major risks by means of risk comparison and risk reduction techniques. These techniques fall into the first two categories of technical risk assessment described above. Although this review was conducted from a scientific perspective and reached significant conclusions about the derivation and use of a 'hard science' framework for comparing risks and setting priorities, its results were recognised as having considerable public policy impact. This is likely to be crucial in terms of implementation.

6. A Washington State Example

In 1988, environmental policy-makers and natural resource managers in Washington State recognised that they required a clear strategy for environmental management. This recognition resulted in the creation of 'Washington Environment 2010', described as an "exercise in environmental ark building" (Miller, 1990).

As part of *The State of the Environment* report published by the steering committee in 1989 (Environment 2010, 1989), the technical committee identified and defined 23 threats to environmental resources, ranging from air and water pollution to hazardous and non-hazardous waste sites and litter. They then assessed these risks using a version of comparative risk assessment that focused on human health risks, ecological risks and economic risks.

Rather than rank all 23 threats directly, emphasis was given to setting priority levels so that threats were placed in six categories with priorities ranked from one to six. It is notable that, for the region being studied, the threats placed at priority level one were: ambient air pollution, point source discharges to water, and non-point source discharges to water.

Comparative risk assessment is described as a framework for assessing environmental issues and highlighting important differences so that limited resources can be applied to best effect. In this way it incorporates aspects of cost-risk benefit balancing. Although this method does provide a clear systematic framework for examining threats or risks, its limitation is that it does not provide concise numerical estimates of risk.

A number of different criteria can be incorporated into this approach to comparative risk assessment, including manageability, potential economic damage, trends, and professional experience and judgement.

The method is extremely appropriate for assessing environmental risk issues because the emphasis is on placing risks into groups according to a grading system and a wide variety of criteria. Environmental risk issues are characterised by a lack of hard data and the presence of uncertainty, as well as the need to take community values into account. This form of comparative risk assessment is able to provide useful answers as to which problems should be tackled first, and to incorporate the above limitations and restrictions.

One of the problems of the general risk comparison approach, as described by Rowe (Rowe, 1980), is that it is very difficult to compare risks with differing characteristics. For example, it is quite inappropriate to compare risks to human health which occur from participation in a voluntary activity or circumstance to those risks arising from an involuntary situation. However, in the context described above, the use of priority groupings generally avoids this type of direct comparison.

7. New Zealand Potential?

Like other economies and social organisations, New Zealand is facing a future where economic resources will be inadequate to tackle all environmental risks. Therefore, we will need to devise ways of *ranking* or *prioritising* risks or hazards. This ranking will require subjective evaluations that incorporate societal preferences as well as economic variables. The method of risk comparison proposed by the USEPA and applied in Washington State, as described, offers an example useful to us. We need to consider this approach further and consider also current European approaches.

In a proposal to the Ministry for the Environment, I have suggested developing this area further with a view to recommending whether we should adapt the United States framework or develop our own separate approach to prioritising and categorising environmental risks. It is notable that the impetus for the USEPA research was recognition of the huge problems associated with waste disposal over a number of decades. We are more fortunate in New Zealand in that our problems are smaller scale and our history of waste disposal is comparatively short, however we are taking longer to recognise the problems and therefore need to act quickly now, both to prevent further abuse of the environment and to recognise and clean up existing problem areas.

The question of determining acceptable risk levels has been examined by many risk researchers, approaching the topic from different backgrounds and disciplines, for a number of years. Much research has centred on increasing understanding of public perceptions of risk as a means of reducing conflict with expert risk predictions. This has led to recognition of the importance of developing suitable communication channels between experts and the general public in order to reach conclusions that result in positive environmental outcomes.

The work I am proposing will follow the path of, firstly, reviewing current progress being made by the USEPA and other international bodies, in terms of the theoretical and practical approaches to risk comparisons used to determine priorities for risk reduction; and, secondly, analysing the specific analytical and scientific techniques being applied. The third stage will be to develop a framework for New Zealand to adopt towards setting priorities for environmental protection.

It is envisaged that the framework developed will provide a basis for guiding policy-makers in establishing approaches to environmental decision-making. Many of the decisions required for evaluation and comparison of environmental risk, leading to the development of methods for risk reduction, will inevitably involve value judgements. Any framework for prioritisation of environmental risk must take explicit account of this and include value structures reflecting current opinion, and must incorporate the concepts of sustainability and the needs of future generations.

Conclusion

Risk assessment techniques are flexible enough to be applied in a number of very different situations and in a variety of different forms. Risk assessment for environmental hazard requires careful examination of the character of the problem, the availability of data and the (apparent) degree of uncertainty before an approach to a specific problem can be selected.

Waste management problems often involve environmental risk and have long-term implications for both natural habitats and human health. Clean-ups tend to be costly and time-consuming and, at times, involve merely shifting the problem to another place or another generation, a practice that is becoming less acceptable to the community.

A scarcity of resources means it is necessary for public agencies to set priorities for action. Risk assessment techniques such as risk comparison approaches can provide a useful approach to setting priorities, however the political aspects of environmental risk mean that greater emphasis must be placed on communicating to public agencies and the community at large.

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RISK ASSESSMENT AND ELECTRICITY DISTRIBUTION IN NEW ZEALAND

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1. Function

The function of the electricity distribution industry is seen as the provision of a public supply of electricity to the population, commercial enterprises and industrial undertakings of New Zealand. An underlying qualification of this function is that the electricity supply be to acceptable standards of safety, reliability, quality and price. Also implied, at least up to the present time, is that the industry should provide leadership by providing independent advice on electricity safety and efficient utilisation in the home or workplace.

Present legislation has largely placed the obligation for inspection and compliance with statute on the electricity supply authorities.

2. History

The electricity distribution industry has a very short history of just over 100 years. In this short time its growth and development has been rapid, and the end-uses dependent upon electricity have expanded rapidly.

Construction standards, safety provisions and quality of supply have been largely industry developed in response to customer demand. These were later documented as Industry Codes, some of which have been incorporated as legislation. Very little assistance was available from overseas experience, because New Zealand was developing its electricity network at the same time as other world leaders and was itself leading in many areas, for example rural reticulation and electric water heaters. One retired electrical engineer who worked as an Assistant Engineer to the Southland Electric Power Board, the first to undertake extensive rural reticulation, commented to me that "...we had to find out how to build the network ourselves as there was no-one to ask".

Of course, many lessons have been learnt the hard way, but the industry has an enviable record for risk reduction and hazard abatement.

3. Public Perception of the Industry

Consumer surveys indicate that the public regards the industry as providing a public service as of right to all; that electricity provides a high reliability energy source which is safe when used correctly; that price has become of greater concern in more recent years; and that independent advice can be obtained from local electricity supply authorities.

4. Perceived Risks

Taking the definition of *risk* and *hazard* from the briefing paper by John Gardenier and Roger B. Keey, that is:

Risk as the probability of a specified loss or harm

Hazard as the potential loss that can cause human, social, environmental or economic harm.

The perceived risks of electricity, excluding the civil works that are essential to the production facilities of bulk electricity, are summarised below:

4.1 Electric Shock

- Death, burns or other injury to the public or users of electricity.
- Electrocution of animals or wildlife.
- Loss of enjoyment, production or injury from small non-fatal shocks, for example, loss of milk due to small potentials in cow sheds.

4.2 Fire

- Electrical faults can cause fires, including buildings and property fires, landscape fires and bush fires.
- Distribution equipment, if faulty, can explode or start a fire.
- Burns or even death can result from fire and very substantial property loss may be caused. (Unfortunately, it has become common practice to blame electricity where the cause of a fire cannot be established).

4.3 Environmental Degradation

The risks of electricity distribution to the environment are the loss of (or gain to) scenic values and all that these may mean in terms of other activity, such as tourism. Possible damage to landscape, for example, access roading, and radio and television interference.

4.4 Dependence Loss

When a service has become so widely used as electricity there is a risk of loss or harm when this service is interrupted because of some unforeseen reason, such as a cable fault, storm or motor accident damaging essential equipment. The industry gives preference for reliability to hospitals, hospices, life support systems, public water and sewage treatment plants and pumping stations, and important public services such as traffic lights, train services and so forth.

Because interrupted supply can cause substantial loss, preference is also given to industrial processors where non-supply can be very costly or even dangerous, for example, metal smelting, refining processes and even to such items as building lifts.

5. Recording of Incidents

The industry has, over the years, kept accurate records of electric shock incidents and these are published from time to time in summary form with widespread distribution. Reporting and recording of other incidents, unless serious enough to invoke public interest, have varied considerably from authority to authority such that data is not readily obtained for the country as a whole. A system of recording durations of non-supply is now underway and useful data will be available in the near future.

6. Causes of Hazard

Electric shock is usually caused by coming into contact with a flow of current, either between equipment or along the ground. There must be a potential difference for a current to flow and it is that flow which constitutes the hazard to life.

Faulty insulation or equipment can place hazardous potential or potential gradients where they can cause harm or loss. A dangerous earth potential rise can be transferred outside the immediate area, for example to telephone users.

Damage to otherwise safe equipment can result from other risks such as contact by aeroplanes or vehicles.

Perhaps the most common causes of damage are those caused by natural forces such as storms, lightning or strong winds.

7. Ignorance or Vandalism

By far the majority of causes of harm or loss are attributable to ignorance, to not thinking or to deliberate acts by persons. Such examples are cutting off locks or removing guards, climbing structures, and, more importantly, simply not thinking — such as using a hair drier in the bath.

Inadequate care when excavating near cables or handling high loads under overhead wires is another serious cause of accident.

Trees planted under lines are a serious hazard if not properly maintained clear of the lines.

Suicide using electricity is perhaps outside the scope of this paper.

8. Inadequate Protection Afforded to Live Equipment

Risk increases if there is failure to provide and maintain adequate safety standards. These standards must be appropriate for the equipment, the voltage, and the location of the live equipment. For example, what sort of fence and clearance distance should be provided to reduce the risk for an extra high voltage substation?

9. Industry Changes Foreshadowed

The electricity supply industry is in the process of being deregulated and reorganised. Already we have seen locally elected Board members on Power Boards be replaced with Board members chosen by the Minister of State Owned Enterprises, and the process of company formation and their future designation as Directors temporarily stalled. Separation of the enterprises into line and energy operations is to start with the subdivision of line costs and energy costs on power bills from 1 January 1992. Further legislation to complete the formation of Power Companies to operate as fully commercial undertakings is being prepared.

These changes are seen as removing many of the statutes and regulations that have been built up over the years, and replacing them with competition for customers, reporting of results and light-handed regulation.

The operating regime needs to provide an affordable means of maintaining adequate and acceptable standards of risk in its operations and for the public in general. Administration costs of the inspection and compliance procedures that will be required must be contained. An industry levy is an easy method of raising finance, but there must be accountability back to the providers and collectors of this finance, which this method will have difficulty providing. For full user pays the costs should go right back to the end-user. Control may then revert back to the insurance company which could require a certificate of compliance with some standard before accepting an insurance risk.

10. Commercialisation and Competitive Forces

Commercialisation of the electricity supply industry will bring about change in the objectives of individual companies. The principle objective is seen as the maximisation of profit moderated by the normal commercial need to keep good customers. There are many non-profitable customers receiving public electricity supply at the present time. Competition will ensure that these customers pay the full cost of their supply or make some other arrangements, such as taking over the ownership and operation of the uneconomic reticulation system. What effect will this change have on containment of acceptable risk? Will this process produce a retrenchment of rural reticulation and, if so, what of the political consequences? It was the rural demand for an affordable public power supply that led to the 1918 Electric Power Boards Act. This Act and its successor, the 1925 Act as amended, have achieved the original purpose, but are they now in fact superfluous?

Pressure will come from large users of electricity trying to reduce their supply costs. This pressure will influence distribution company decisions, including expenditure on risk management for uneconomic systems.

11. Privatisation

Ownership of the industry is yet to be determined, however it is possible that full privatisation will follow commercialisation. This is seen as another challenge for the probability component of risk management, if industry forces alone are relied upon to provide the input.

Private ownership is most likely, at least in the medium term, to transfer outside New Zealand because of the investment required and the profits that could flow from largely captive customers. This will make the decision-makers even further removed from the customers. The proposed light-handed regulatory regime is a further incentive to overseas ownership.

Although these problems can be treated with regulatory change, two difficulties could result: the reaction time of regulatory action — it has taken many years for even simple changes in the past; and the threat of high compensation to established owners if the commercial framework is changed adversely. Such fears may be unfounded if the original legislation is given adequate consideration.

12. Standards for Risk Criteria

Consideration needs to be given to how these will be determined and implemented. In the past they have been formulated by industry working parties comprised of the most experienced personnel available, working mostly voluntarily, whose output has resulted in the Codes of Practice and Statutory Regulations.

Choices of Standards could be between:

- Adoption of international Standards where suitable, perhaps with local input or modification, if possible, to address local problems.
- Production of local Standards.
- Over-reaction to specific problems and public concern driving legislation.
- Other?

13. Changes in Technology

New technologies will provide new opportunities and require a re-assessment of existing criteria and the implementation of change. There needs to be a climate for improvement from change and an acceptance of new materials and methods, even if not initially commercially attractive, for example, underground wiring systems.

The New Zealand Committee for the Co-ordination of Power and Telecommunication Systems was formed in 1985 with the objective of bringing together representatives from the Electricity Supply Association, Telecom, Electricorp, Railways Corporation and the Ministry of Commerce to prepare guidelines on a number of electrical matters of importance to the parties. Working parties were set up to investigate and prepare technical guides on the following subjects:

- Cost Sharing
- Cable Sheath Bonding
- Earth Potential Rise
- Hazards
- Neutral Earth Resistance
- Cable Trench Sharing
- Single Wire Earth Return

This important work has been industry funded, but once again the input of industry expertise has been largely unpaid. The 1990/91 approved budget was $63,000, with most of this money going to the DSIR Applied Mathematics Division to produce a Hazards model for the Hazard working party to calculate the probability that an individual using a telephone will suffer a fibrillation fatality in one year.

Conclusions

Public perception of risk associated with electricity distribution is unrealistic. Great confidence is placed at present in local electricity authorities to provide a completely safe supply of electricity. This is based upon past performance and past extensive public education programmes.

Statistics confirm that the majority of fatalities involve users of appliances in the home or workplace where some safety precaution has been neglected. Electrical workers are a small percentage of these statistics, with non-involved public even lower down the list. Nevertheless, a public hazard does exist and potential loss needs to be considered.

Consideration needs to be given to mechanisms to address and contain to an acceptable figure electricity risks in the future deregulated and commercial environment to which the electricity distribution industry is committed.

Reporting of electrical incidents should be maintained to provide a reliable statistical base from which to monitor performance and formulate future policy.

RISK ASSESSMENT OF INDUSTRIAL AND NATURAL HAZARDS

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1. Introduction

Occupational Safety and Health (OSH) is one of four individual business units in the Department of Labour. The ultimate objective of OSH is to minimise the economic and social costs of workplace injury and illness, and to ensure that no worker or public group suffers a disproportionately high level of injury or illness from work activity. The intermediate objective is a reduction in the frequency and severity of workplace injury and illness.

Current legislation administered by OSH is either hazard-based (for example, Machinery Act 1950, Asbestos Regulations 1983) or deals with particular types of workplace (for example, Construction Act 1957, Factories and Commercial Premises Act 1981). The major difficulty with this approach is that some hazards are covered in detail in some industries while similar hazards in other workplaces may not be covered at all. The volume and complexity of the legislation would have to be increased greatly if an attempt was made to ensure wider coverage under the current approach. The current Health and Safety in Employment Bill, presently being considered by Parliament, will attempt to enable all hazards to be treated in the same manner. This will require a different approach to legislative coverage.

2. Risk Criteria

The OSH service ensures uniformity in its standards of compliance throughout its 18 field offices through the criteria contained in the legislation it administers. The Factories and Commercial Premises Act 1981, Machinery Act 1950, Construction Act 1959, Bush Workers Act 1945, Dangerous Goods Act 1974 and the Explosives Act 1957 form the basis of this legislation. The more specific Regulations complement these Acts for specific occupational processes or hazards, and Codes of Practice offer a means of compliance with the parent Act.

In this financial year OSH is running a number of programmes in its prevention and compliances services which relate to identifying workplaces or processes as a result of hazard or risk information. They include:

2.1 High Priority Workplaces by Performance

This programme will target 1600 'under-performers'. Selection of under-performers will be based on criteria such as:

- consistently low compliance with minimum occupational safety and health standards;
- known high injury/illness occurrences; and,
- lack of commitment and/or ability to manage risks.

2.2 High Priority Workplaces By Hazards

Inspections of 15,500 workplaces in which people may be adversely affected by severe hazards or risks will be selected. High priority workplaces are those in which work practices, substances, processes, equipment or machinery used have been identified as having a high hazard or risk to persons engaged or employed.

2.3 National Projects

A total of 3,000 workplaces will be audited to evaluate exposure to or adverse affects from chemicals, noise and manual handling. These projects have been identified as a result of high ACC payments and will run over a minimum three-year period.

3. Risk Perception

Lay perception of risk is generally not based on objective scientific reasoning, but can play a part in establishing OSH's priorities. OSH is making an attempt to base its priorities on either high risk activities or processes; for example, tree felling, or low risk-high hazard processes or activities. The latter is often of considerable public concern; for example, amusement devices and tank farms.

4. Risk Quantification

4.1 Source Data

The OSH service has many sources of data available for risk quantification. Risk can be quantified from either directly assessing the risks in the workplace or compiling 'end product' (that is, actual accident) data.

Accident data is an important base for quantifying risk. OSH legislation requires that an occupationally-related accident or illness which requires someone to be off work for 48 hours or more be reported to OSH.

Although this information is valuable, our estimates are that only about 20 percent of such accidents or illnesses are reported to OSH.

OSH also has access to ACC injury data. At present this only provides OSH with claims by industry type and therefore does not allow OSH to target individual workplaces where relatively high claims to ACC are occurring. OSH is presently negotiating with ACC to overcome this issue.

OSH also surveys its clients in the workplace. By asking employers and employees statistically relevant questions, OSH can gain a perspective on attitudes toward safety and health. This is important, considering the impact of human error and negligence in causing accidents. These surveys also check compliance with mandatory and voluntary safety standards.

4.2 Assessment

The OSH service has recently implemented a new information monitoring database for its field staff. This database is designed to hold all data on inspections, accident investigations, compliance problems, and so forth. One part of the database will be a section on risk quantification. This section is being developed at present and, if successful, will allow inspectors to prioritise their work according to assessed risk.

In this method, employment practices and processes will be assigned a value of maximum impact on persons, depending on the inherent hazards involved. These impact values will be derived from a vulnerability scale that has been defined for the sake of relativity. The vulnerability scale will compare a scale of acute and chronic injury and illness to an impact index. The inspector will note this impact value and, based on experience, will assign another value upon personal inspection of the premises.

This second value will be the proportion of the impact from the workplace hazard that is present in this particular workplace, and will be multiplied by the derived impact value to calculate the risk for this specific practice or process. In essence, the inspector will be assigning a perceived approximation of frequency of occurrence for the hazard associated with a particular practice or process.

Estimates of risk can be gained in the workplace by comparing monitored data with accepted published values. Monitoring can be biological (for example, lead levels in blood), environmental (for example, toxic concentrations in air), or chemical (for example, testing to quantify dust explosibility). Comparison of monitored and published risk levels (for example, threshold limit values) gives a comparative risk assessment.

Premises can also be assessed for potential risk on the basis of how they compare with required safe practices, as specified in OSH legislation or other accepted standards.

4.3 Community Risk

OSH has a number of responsibilities relating to risk to the public. These include risks arising from work activity, such as protecting the public from work activities on construction sites (for example, objects falling from high-rise construction sites), and more direct measures to protect public safety. These include ensuring the safety of amusement devices under the Amusement Device Regulations 1978, protecting the public by approving tank wagons, gas cylinders, containers and bulk storage installations under the Dangerous Goods Act 1974, and protecting the public from improvised explosive devices (IEDs) under the Explosives Act 1957. Another role OSH has under the Explosives Act is the approval of the sale of fireworks for display and retail purposes.

OSH is also developing regulations for Industrial Major Accident Hazards. These regulations will assess risks and hazards in plants of such magnitude that an on-site incident could have off-site consequences.

The plants that will have to comply with this legislation will have been selected according to specific criteria, related to quantities of specific hazardous chemicals on-site and certain process conditions (similar to the UK Control of Industrial Major Accident Hazards Regulations 1984). There will be two tiers of threshold quantities for two levels of assessment. More complex methods of consequence modelling, such as iso-risk contouring, would be useful for the type of report required by these regulations, and would be particularly useful in built-up industrial areas where significant risk contours may pass over site boundaries or where several plant contours may overlap.

RISK ASSESSMENT – A REGIONAL COUNCIL PERSPECTIVE

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1. Introduction

The Waikato Regional Council has not, to date, made very clear distinctions between risk quantification, risk perception and risk criteria. Rather, it has adopted preventative management strategies and policies for high risk problems and potential problems.

In accordance with modern management practice and performance reporting requirements, each year the Council adopts an Annual Plan and the management of significant risks features throughout the plan.

2. Annual Plan

Some examples that feature in our Annual Plans[1,2] are:

- Flood risk and flood warning.
- Obtaining disaster insurance for flood alleviation schemes.
- Encouragement of dam-owners such as Electricorp to undertake dam-break analysis.
- Identification of the potential for natural hazards and planning for their mitigation[1].
- Civil Defence planning on a regional basis, especially to improve public awareness of hazards and personal response to emergency situations[1,2].
- Ensuring sustained maintenance of Bovine Tb control programmes.
- Minimising and ensuring effective disposal of the region's waste, including hazardous waste[2].

3. Flood Risk and Flood Warning

The Regional Council inherited major flood alleviation schemes that were either completed or partially completed. Total capital investment in those schemes is in excess of $250M at today's prices.

Floods still represent the most likely natural hazard to occur in the Waikato region, hence the Council operates a large telemetry system of rainfall and river recorders linked to control centres at Te Aroha and Hamilton.

The structural flood alleviation schemes, embracing earthen stopbanks, flood channels, berms, erosions and control works, pumping stations and floodgates have been described elsewhere[3]. Design standards have been based on the probability of recurring floods with the empirical 100-year flood as the design norm. Some asset value variation has seen a two percent probability annual risk flood ascribed to urban areas, with a three- to ten-percent annual risk for some rural and tributary systems. The one percent probability has been used for the main arterial system. A move to the concept of percentage risk is seen as giving a better public understanding of the probability of flood events. The historic 100-year flood has led to a number of misunderstandings. The probability method is consistent with modern public weather forecasting which gives, say, a 30 percent chance of rain on a particular day. Such a concept should be more easily understood by the public at large.

In recognition of the possibility of overtopping, or the less likely failure of flood defences, the early warning telemetry system gives the Regional Council a valuable head start in giving advance warning of high river levels to territorial local authorities and civil defence. The telemetry system is manually operated, but a three-year upgrading plan is in hand to achieve more automatic forecasting.

4. Disaster Insurance

In recognition that flood defences may fail from time to time under extreme flood conditions the Regional Council has taken out disaster insurance for its flood alleviation schemes. The strategy has three facets:

- First, a $250,000 excess which is covered by a capital reserve;
- Second, a $2.5M disaster cover which represents about one percent of the capital value of the asset. Given that there is an approximate one percent annual risk of overtopping, the 'exposure' of the insurance company is seen as reasonable;
- Third, for a disaster in excess of $2.5M the Regional Council believes that a significant regional disaster will have occurred and that some centrally based funds will contribute to restoration. Here I am referring to a Cyclone Bola or similar scenario.

As a responsible asset manager, the Regional Council is reviewing its maintenance arrangements to ensure the structural and hydraulic integrity of its flood defence assets.

5. Dam Break Analysis

The risk of annual flooding in the main Waikato-Waipa river system has been further reduced by a contract between the Waikato Regional Council and Electricorp for the use of discretionary flood storage in the Waikato Hydro System. The main advantage is the facility to avoid coincidental flood peaks in the Waikato and Waipa Rivers at their Ngaruawahia confluence. The Regional Flood Controller can exercise some judgement to give more security against high risk floods in the Waikato River below Ngaruawahia by arranging the release of Waikato waters out of sequence with the natural flows from the Waipa River.

The contract known as the Waikato Flood Management Rules has been reviewed to incorporate the additional flexibility provided by the refurbishment of Arapuni

The Regional Council has been especially pleased with the further initiatives taken by Electricorp, as owner of the Waikato Hydro Chain, to undertake dam break analyses. Two have been completed and others are planned[4,5]. The information thus gained has been a reassuring and useful input into regional Civil Defence planning.

6. Identification and Mitigation of Natural Hazards

The Waikato Regional Council has recognised that effective flood management and mitigation of natural hazards, functions now reinforced by the Resource Management Act, have many facets. To summarise, I have addressed:

- Structural flood alleviation or defence schemes
- Disaster insurance
- Flood warning
- Flood storage in dams
- Dam break analysis

Two other facets also need to be reviewed: Flood management planning is dealt with in the next section and Civil Defence is dealt with in Section 8.

7. Flood Management Planning

As a working example, the Executive Summary of the Draft Huntly Flood Management Plan is given[6]. A draft plan for the coastal community of Te Puru is also complete, and another covering Te Awamutu is substantially complete and is being used as a pilot to test the advantages of Geographic Information Systems and Digital Terrain modelling. A Regional Coastal Plan for coastal areas generally is expected to be drafted by October 1993.

The Waikato Regional Council (WRC) has a statutory responsibility under current legislation to minimise damage caused by floods and erosion. To exercise this responsibility with regard to Huntly township, this Flood Management Plan has been prepared in conjunction with the Waikato District Council (WDC).

A joint Council approach was adopted because many of the mitigation options suggested by the Plan will be implemented through provisions of the district scheme covering the Huntly area. In addition, the District Council is the first point of contact for people wishing to develop their land or property in Huntly.

The main objective of the Plan is:

> *To identify, mitigate and avoid the flood hazard pertaining to the Huntly area to the fullest extent practicable, without placing unnecessary restrictions on the rights of individual property owners.*

The Huntly area is prone to flooding from three sources. The first is the Waikato River, from which the town is protected by the Lower Waikato and Waipa Flood Control Scheme stopbanks. Secondly, localised flooding can occur from ponded stormwater, particularly when drainage is restricted by high river levels.. Thirdly, the numerous lakes in the area tend to rise in response to localised rainfall events.

These three potential sources of flooding have been the subject of previous studies, and in 1989 a flood hazard map and associated ordinances were inserted into the Huntly Borough District Scheme. With subsequent local government reorganisation, boundaries of this map require extension. In addition, revised ground survey data and improved hydrological information have enabled the extent of potential flooding to be refined.

Four flood hazard maps have been prepared that show the spatial extent of flooding for the one percent event (the biggest flood that might be expected to occur once in 100 years) and the probable maximum flood. Also, an indication of the hazard potential, based on the combination of depth and velocity, has been made.

Having defined the extent of the hazard, a range of mitigation options are proposed. These fall into two categories:

(i) Modifying the flood event; and,

(ii) Modifying flood loss susceptibility.

Under the first category, several possible physical works are identified, including additional stormwater pumping stations, upgrading the Huntly College embankment and placing flapgates on stormwater outlets to Lake Waahi. Due to a lack of central government subsidies, the cost of these works would have to be largely borne by the residents of Huntly.

A series of planning or development controls are then proposed that build on the existing provisions of the Huntly Borough District Scheme. Minimum floor levels are recommended to ensure that new buildings are above the likely one percent event flood levels. Existing district scheme restrictions relating to the infilling of areas prone to ponding are to be retained. The intention of these restrictions is to ensure that ponding levels are not raised by future development.

Advice is offered to prospective developers and existing property owners on appropriate building materials to use in flood-prone areas, and on measures that can be taken to reduce the damage potential should a flood occur. This advice will be promulgated by the Waikato District Council through its building permit role.

The Plan summarises the flood warning system that applies to the Waikato River in times of flood. This essentially involves WRC staff monitoring weather reports and river levels, and advising WDC staff of potential flood situations. Should a major flood event occur, then the WDC Civil Defence organisation would become involved in warning and evacuating people in the at-risk areas. This process is briefly addressed in the Plan, with more details contained in the stand alone Waikato District Council Civil Defence Plan.

Responsibility for the implementation of each of the above mitigation options has been assigned to either the WDC or WRC. This will provide a means of monitoring the effectiveness of the Plan and the appropriateness of mitigation options. Finally, the review of this Plan will be linked to the review of the operative district scheme for the Huntly area.

8. Civil Defence Planning

The Regional Civil Defence Plan[7] sets out detailed direction on the actions and procedures to be followed by Council and other organisations in the event of a Civil Defence emergency. The emergency may directly or indirectly affect the region and includes a national emergency.

The Plan provides a basis for planning, training and publicity for all Civil Defence organisations in the region. In an emergency situation it is therefore possible to mobilise, co-ordinate and assist in the use of all or part of the region's resources. Such resources are provided by emergency services, agencies of central, regional and local government, community organisations and individuals.

In essence, the Plan provides the framework for a state of preparedness, sets out clear procedure to be followed in the event of an emergency, and ensures all organisations involved are aware of their roles and responsibilities.

The region does not take over the duties of other bodies, but through liaison and mutual co-operation, co-ordinates effort, allocates priorities for action and provides assistance. These efforts are directed at achieving the three goals of the civil defence system:

- To prevent the loss of life
- To help the injured
- To relieve personal suffering and distress.

The plan is prepared in accordance with the Civil Defence Act 1983 and the National Civil Defence Plan, and also includes reference to supporting Standard Operating Procedures (SOPs). These are documents setting out detail (which may change from time to time) on organisational, operational and training matters.

The major components of the Plan are as follows:

- Discussion of potential threats to the region arising from natural and manmade causes.
- Regional response to an emergency and procedures for formal activation of regional Civil Defence headquarters (CDHQ).
- Specific matters of emergency service response (disaster recovery, warning systems, law and order, fire services, medical and public health, public information, welfare, transportation, communications, energy and supply).
- Preparation and training.

The Waikato region is vulnerable, in varying degrees, to threats of disasters from natural (earthquakes, volcanic eruptions, cyclones and tornados, flooding, tsunamis) and 'man-made' causes (failure of structures, disposal of hazardous materials). For earthquake and volcanic eruptions the region is likely to be affected by occurrences in adjacent areas. Cyclones, tornados and tsunamis may directly affect the region and allow for only limited warning. Flooding must be considered a significant threat in the region, notwithstanding flood protection works.

Should a Civil Defence emergency occur within the region which cannot be dealt with by any territorial local authority, then a regional Civil Defence emergency may be declared for all or part of the region. The Plan sets out, in the event of a regional emergency, the functions and powers of the Regional Council, procedures for declaring an emergency, immediate response actions, responsibilities of named personnel, and activation of the regional headquarters.

Chapters of the Plan dealing with specific matters of emergency service response (disaster recovery, warning systems, law and order, fire) set out the specific aims of work or action in particular areas, responsibilities of different organisations, how efforts will be co-ordinated, priorities for action, and the Director for Local Planning. For example, welfare:

- **Aim** *"... to establish the welfare system in the region in order to provide for the welfare needs of people in all stages of a disaster requiring a response from the region."*
- **Functions** Feeding and catering, accommodation, evacuation, clothing, personal services, registration and inquiry, recovery.
- **Responsibilities** [of the] Regional Controller, Department of Social Welfare, local authorities, community groups.

The preparation and training component of the Plan provides detail on regional co-ordination of these aspects and direction as to appropriate training to be undertaken by Civil Defence personnel with regional and local authorities.

9. Bovine Tb Control Programmes

The spread of bovine tuberculosis represents a risk and major threat to the agricultural sector. The Regional Council assumed the functions of Pest Boards from 1 November 1989 and had to quickly establish a regional framework within which control programmes could be implemented.

The Regional Council recognises that the expertise for understanding the disease and its spread resides primarily with MAFQual, its Animal Health Board committee, and Massey University, through its Veterinary Continuing Education Unit. The fur trade industry and the pest control industry are also valuable repositories of information.

For its own part, Regional Council has gained staff from the former Pest Boards and their expertise has enabled Council to co-ordinate pest control over the Waikato region.

An early policy decision abandoned special area rating for pest control in favour of funding from the general rate. The belief was that the control of pests and Bovine Tb, in particular, was of benefit to all regional ratepayers.

The prime animal groups for protection are the dairy herds of the region. However, the diversification of the agricultural industry means that other herds, such as deer, must be incorporated into the control and reaction programmes. Each new diversification brings a potential escalation of the problem. Alpacas and llamas are examples.

The Council's approach is to ensure that effective buffer zones are maintained between known infected areas and non-infected areas, or areas with a low incidence of Bovine Tb.

Control operations involving poisoning of possums bring a secondary set of risks to be weighed in the decision-making process. However, it must be recognised that the Regional Council is acting as a 'contractor' to MAFQual and in some areas also to the Department of Conservation.

The normal precautions of a Department of Health clearance, public notices, advice to the police and farmers are taken in advance of poisoning operations.

Secondary risk includes the accidental poisoning of stock, dogs or watercourses.

While not addressed in this paper, the Regional Council is also involved as a co-ordinator for the control of noxious plants, and the recent invasion of water net is a classic example of how the risks to be managed change from day to day.

10. Hazardous Wastes

Regional Council is intimately involved in managing the risks of chronic and acute effects of toxic substances, and has taken a number of initiatives in cleaning up some legacies of toxic waste in the region. The former Waikato Carbonisation Plant at Huntly has had toxic liquids transported to Kinleith for incineration. Plans are also underway to detoxify the Tui mine tailings in Te Aroha.

The packaging of goods provides a significant volume of domestic waste and will be a factor in solid waste disposal[8].

The WRC has developed a draft Regional Solid Waste Management Plan[9] which will form the basis of an integrated approach to solid waste management in the Waikato region in the future. A recent study has located landfill sites in the region, including identifying existing and future refuse volumes.

The concerns of the WRC follow from several factors:

- Absence of a cradle-to-grave facility for handling hazardous wastes.
- Longevity of hazardous wastes.
- Absence of regional treatment facilities.
- High cost of legitimate disposal.
- Risk of unauthorised dumping.

Summary

Our position paper has been written from a management viewpoint. The risk elements have been assessed in a qualitative way, but quantified from an empirical or probability viewpoint that is proportional to the length of experience with the topic. The result is that the risks associated with flooding are better known and quantified than, say, hazardous wastes. However, with the passage of the Resource Management Act, we have a better legislative basis for the mitigation of natural and man-made hazards.

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RISK ASSESSMENT AND THE PLANNING PROCESS

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1. Historical Planning Approach to Risk Management

The historical approach to the management of risk from industrial activities in land use planning has been to segregate industries into zones, depending on whether they were considered to be heavy or light industry. District Planning Schemes, the main mechanism for planning control, commonly provided for three industrial zones:

- Industrial A zones for light service industry located adjacent to residential areas;
- Industrial B zones for general industry; and
- Industrial C zones for heavy and/or noxious industry, usually located away from residential and commercial areas.

In effect, risk from industrial activity was managed by separating the activity from more sensitive land uses such as residential. Some noxious industries, including offensive trades as listed in the Health Act, were excluded as permitted activities from all industrial zones.

In the late 1970s and early 1980s District Planning Scheme controls became more sophisticated, with lists of industrial uses being replaced with lists of industrial processes. The schedule of processes as set out in the Clean Air Act 1972 was also used to segregate industries by way of 'pollution performance standards'.

More recently, controls on the storage and use of hazardous substances have been introduced into the industrial and commercial zone controls of some District Schemes. Control is exercised through schedules of hazardous substances with specified quantity thresholds. The storage and use of quantities in excess of those specified is controlled (through conditional use procedures which provide for public scrutiny), or is prohibited.

In dealing with the question of natural hazards such as flooding, the usual approach in District Planning is to define the flood plain with a 100-year return period for each particular catchment. The flood plain is defined on the planning maps and restrictions are placed on the use of land within the flood plain. Buildings and storage are usually prohibited in such areas. The 100-year return period standard has now been adopted by most catchment authorities in New Zealand and is generally recognised by the public as an acceptable standard.

2. Examples of Risk Assessment in the Planning Process

With the greater availability and increased use of LPG as a motor vehicle fuel in the early 1980s, the storage of LPG became a widely debated planning issue. One of the issues raised concerned the distinction between isolation distances required under the Dangerous Goods (Class 2- Gases) Regulations 1980 (primarily for the protection of the LPG storage facility), and separation distances designed to separate the facility from neighbouring land uses such as housing. In dealing with this issue and other issues of LPG storage, quantitative risk assessment was seen as a useful tool to assist decision-makers (local authorities and the Planning Tribunal) in reaching a decision on a particular proposal, for example, an LPG tank for a service station.

Risk assessment techniques were also used to support the application by Liquigas Ltd for a 3000 tonne bulk LPG storage and distribution depot in Manukau City (1982/83).

In 1982 the then Ministry of Works and Development commissioned the preparation of guidelines for dealing with planning applications for LPG storage. The draft guidelines were based, in part, on risk assessment studies on LPG facilities carried out by TNO (Holland) for the former Liquid Fuels Trust Board. At about the same time, the New South Wales Department of Environmental Planning produced draft planning guidelines for storage of LPG at service stations. These guidelines were also based on risk assessments, in this case carried out by agencies in Australia.

Another example where risk assessment has been used in the planning process to assist in decision-making was an application by Ansell Steritech Ltd for an industrial gamma irradiation plant in Manukau City. Information presented at the hearing in support of the application included an environmental impact assessment and audit, a site-specific seismic hazard study and a quantitative risk assessment and audit.

3. Risk Assessment as an Aid to Decision-making

Risk assessment in the planning process in New Zealand has been used in the past primarily to assist a decision-maker in assessing the acceptability of a potentially hazardous industrial activity in a particular locality. In addition, early identification of potential hazards would be relevant as part of the site selection process. Risk assessment could also be utilised to assist in making decisions on appropriate development in the vicinity of an existing hazardous industrial facility. A further possible use would be the application of risk assessment to existing industrial facilities to provide some guidance as to the acceptability of the activity and to possible risk reduction measures that may be implemented.

The value of risk assessment to decision-makers in the planning process will depend partly on the extent of the information presented. Clearly, an analysis that simply presents risk numbers will be of little value. It is important that the assessment provides a full description of the various hazards identified and the probable consequences in the event of an accident occurring.

The assessment should also include a number of proposals for reducing risk levels, such as:

- Additional safety features and improved operational procedures
- Alternative locations
- Reduction in levels of activity or storage volumes.

Alternative options to the proposed activity should also be discussed.

4. Risk Perception

The other important area to be considered is the question of risk perception. In arriving at a decision on a proposal, the decision-maker — be it a local authority or the Planning Tribunal — is required to decide whether or not the risk inherent in the proposed development is acceptable. Decision-makers need to be able to compare the level of risk with other risks commonly encountered in society or with other established criteria to determine, as objectively as possible, whether a risk is acceptable or not. In this evaluative process they have to take account of the concept of voluntary and involuntary risks. There is a difference, in acceptability terms, between voluntarily accepted risks and imposed risks. It is generally found that people are willing to accept a higher level of risk for voluntary activities than for involuntary ones.

While most industrial safety legislation in New Zealand is primarily concerned with providing safe workplaces (although this may also improve safety for surrounding land uses), in land use planning the main concern is the effect of a proposed activity on surrounding land uses such as residential areas. In the planning process, decision-makers are therefore dealing mainly with the question of involuntary risk.

The problem faced by the decision-maker is trying to establish an acceptable level of involuntary risk. Obviously, what is acceptable or unacceptable varies from individual to individual. It also varies over time — as people become familiar with a particular activity, its associated risks may move from being initially unacceptable to being accepted. In some cases risks may only be acceptable when they are compensated by certain advantages which people associate with the particular activity.

With regard to the question of public perception of risk, in the High Court decision — *Allens Service Station vs Glen Eden Borough (1985) 10NZTPA400*, the judge found that psychological health is an aspect of total health, and that fear (in this case neighbouring residents' fear of a disastrous escape of gas from an LPG storage tank) is a natural human reaction to certain circumstances. Psychological health was therefore found to be a relevant planning consideration, to be considered objectively. The judge concluded that if fear and consequential harm to psychological health (actual or potential) is established on the evidence, its weight and significance are to be determined objectively along with all other relevant considerations.

In this case, which involved an LPG storage facility at an existing service station, while the technical evidence pointed to the risk of the facility being 'acceptable', the judge held that the fears of nearby residents — despite the fact that those fears may be considered by some parties to be irrational — were a proper planning consideration to be taken into account in making a decision on the proposal.

In dealing with the concept of risk perception, the political decision-maker in planning applications is likely to take strong note of how the risk of the proposed activity is perceived by members of the public who may be subject to the involuntary risk. The decision-maker at this level is also directly accountable to the public. However, judicial decision-makers (for example, the Planning Tribunal) are likely to take more note of risk quantification.

At present in New Zealand there are apparently few guidelines for assessing what is acceptable risk from a public perspective. This may simply be a case of educating planners, decision-makers and the public on what information is available. A number of overseas agencies have formulated risk assessment criteria for various situations. The applicability of this information to the New Zealand situation needs to be considered. This is an area where more research may be required if risk assessment techniques are to be more widely used in the planning process. In formulating risk criteria, it is necessary to distinguish between individual risk and societal risk.

5. Resource Management Act 1991

The Town and Country Planning Act 1977, on which the planning process was formerly based in New Zealand, was repealed (along with other resource legislation) by the Resource Management Act 1991. Under the new Act, emphasis has shifted to the sustainable management of natural and physical resources and the control of adverse effects. The expectation is that land use activities will be permitted to become more 'mixed', with the result that greater use of risk assessment to identify possible adverse effects and to assist in the decision-making process is likely to eventuate.

The term ***effect*** is defined under the Act and includes: "any potential effect of low probability which has a high potential impact". Risk assessment would be a useful tool in assessing these types of effects.

In making an application for a Resource Consent under the Act, one of the matters to be included with the application is an assessment of any actual or potential effects the activity may have on the environment, and the ways in which any adverse effects may be mitigated. Schedule 3A to the Act sets out matters that should be included in an assessment of effects on the environment and states that:

> *Where the activity includes the use of hazardous substances and installations, an assessment of any risks to the environment which are likely to arise from such use [should be undertaken].*

Clearly, risk assessment techniques play an important role in providing information on risks to the environment, as required in applications for resource consents.

6. Main Points

- Risk assessment should essentially be seen as a tool to aid the decision-making process and not as a means of providing a final answer.
- To be useful in the planning process, a risk assessment study should include a full description of hazards identified and likely consequences in the event of an accident occurring. It should also include proposals for reducing the levels of risk and explore alternatives to the proposed activity.
- Publicly acceptable criteria for assessing risks are necessary for the wider use of risk assessment in the planning process.
- The provisions of the Resource Management Act 1991 are likely to result in greater use of risk assessment techniques to determine the effects of hazardous activities.

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RISK ASSESSMENT OF VOLCANIC HAZARD

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1. Definition and Scope

Volcanic hazard is a naturally occurring geologic condition or phenomenon of volcanic origin that presents a risk or is a potential danger to life, property, society and the environment.

Volcanic hazard also includes, at least in a geotechnical engineering context, those conditions which are created or destabilised in some way, by the action of people.

To this extent we should consider not only volcanic activity, but also unusually difficult or potentially hazardous ground conditions in volcanic terrain. These conditions have either presented extreme difficulties and dangerous situations to engineering projects (for example, Prebble 1969, 1986) or have resulted in failure (Hatrick *et al.* 1982, Jones *et al.* 1983, Prebble 1984, Oborn 1984).

Volcanic hazard is therefore twofold:

(i) Danger from future activity

(ii) Danger from the deposits and phenomena resulting from previous activity: this aspect is referred to as our *volcanic legacy*.

2. A Summary Description of the Hazard

The types of volcanic hazard are summarily described as either *active volcanism* (volcanic activity) or as *hazardous volcanic legacy*.

2.1 Volcanic Activity

Scientific and technical literature on this topic depends upon observation of actual phenomena, and of their deposits. These are compared with deposits in the geologic record, from which assumptions about past phenomena are then constructed. Reading the stratigraphic record of active and past volcanoes in this way enables a sequence (which may be incomplete to a varying and unknown degree) of activity over a geologic period of time to be built up (for example, Crandell, Mullineaux and Rubin 1975, for Mount St Helens volcano in the Cascade Ranges of northwest USA).

The nature, magnitude and recurrence of various kinds of volcanic activity can be established from such sequences. Some types of activity, at very large magnitudes, have never been witnessed. These are understood mainly from the geologic record and the physical and chemical nature of their deposits, and from geomorphology. Large magnitude rhyolitic ignimbrite eruptions such as those from the Taupo Volcanic Zone are an example (refer to Wilson *et al.*, 1984).

The types of eruption and nature of the hazard has been summarised by Latter (in Gregory and Watters, Eds., 1986.)

Three major categories of volcano can be recognised, each with a characteristic behaviour.

2.2 Rhyolite volcanoes (volcanic centres)

Several rhyolite volcanic centres, each containing a number of individual rhyolite volcanoes, can be identified within the Taupo Volcanic Zone between the Bay of Plenty and immediately south of Lake Taupo (Cole, 1984). These centres are dormant rather than extinct (Latter, 1986) and so constitute a hazard. Their products have been mainly:

- ***Ignimbrite***
  A high density flow which is a very hot mixture of volcanic gases and ash, produced by an explosive eruption. Ignimbrites also include scoria, pumice and large blocks. Temperatures may exceed 600 °C with speeds of 100 km/hr for *nuée ardente* (or 'glowing avalanche') eruptions, as cited by Costa and Baker (1981:102-103). They also refer to ash-flows of larger extent (160 km), huge volumes (hundreds of km^3) and velocities of perhaps 200 km/hr. Similar volumes (10-100 km^3) are referred to by Latter (1986).

- ***Pyroclastic surge/base surge***
  A ring-shaped very hot cloud of gas and suspended solid debris moving radially outwards at very great velocity as a density flow. These ground-hugging turbulent gas-rich flows could be destructive 10-20 km from the vent (Latter, 1986). They emanate from the base of a vertical eruption column, or other explosions.

- ***Air-fall tephra***
  Showers of ash, scoria and (nearer the vent) large blocks of material ejected aerially as an eruption cloud. Fall-out of material from the cloud can blanket areas of 1,000 to 10,000 km^2 to a depth of more than 30 cm. Ballistic blocks are hazardous over a range of 5-10 km from source (Latter, 1986).

- ***Lahars (debris flows and mud flows)***
  Water in streams, rivers and lakes, or from snow and ice, mixing with the pyroclastic and ignimbritic material and with airfall tephra creates a mud flow, or debris flow if larger size blocks are involved. These could be destructive as far as the coast and could inundate not merely the river channel, but the whole flood plain.

- ***Floods***

  Flooding and excessive sedimentation (or aggradation) could be an on-going hazard as the vast plug of choking eruption debris works its way down the river valley systems leading away from the eruption zone. Grade levels of streams may well be considerably raised, bed-load substantially increased, and wholesale diversion and re-distribution of channels could have taken place.

- ***Tsunamis***

  Destructive waves could be generated in lakes, and in the Bay of Plenty.

- ***Lava domes and flows***

  Latter (1986) refers to domes and flows, with hot debris avalanches breaking from their oversteep slopes, as a late phase of rhyolitic volcanism occuring close to the vents.

- ***Phreatoplinian explosions***

  Explosive eruption columns sited in lakes or the sea could blanket wide areas with mud and debris.

2.3 Andesite - dacate volcanoes

To the north and south of the Taupo Volcanic Zone are andesitic-dacitic strato-volcanic cones. These include White Island in the Bay of Plenty, the Tongariro National Park volcanoes in the south, Taranaki/Egmont out to the West and other domes in the northeast (Edgecumbe and Tauhara).

Hazards include:

- ***Lahars*** — including those capable of deposition, damage and pollution to the coast.
- ***Debris avalanches*** — from a collapse of a sector of the volcano, over wide areas of the surrounding ring plain and foothills.
- ***Pyroclastic flows*** — smaller than rhyolitic ignimbrites but destructive potentially to 10-20 km or so.
- ***Air fall tephra*** and ***basaltic ejecta***
- ***Pyroclastic surges/base surges***
- ***Lava flows***
- ***Tsunamis*** and ***waves*** generally — from large explosive eruptions and collapse of all or a sector of the volcano, in the Bay of Plenty or further offshore (for example, Kermadec Group of Islands).

2.4 Basalt volcanoes

Relatively young basaltic fields exist at the Bay of Islands (Kerikeri area), Whangarei, Auckland and Bombay Hills. Most of these are dormant, and they are monogenetic, except for Rangitoto where there is evidence of more than one eruptive cycle (Latter, 1986). Hazards from these basaltic fields are especially important in areas where there is much at risk, such as Auckland. The volcanoes of the Auckland urban region and its fringe would be regarded as multiple vents on one large volcano, or a single field.

Hazards from these basalt volcanoes include:

- ***Explosive eruptions*** (phreatomagmatic) — where rising lava encounters ground-water and surface water in low-lying or offshore areas.
- ***Explosive base surges*** of hot gas and entrained rock particles. According to Latter these can travel across water and so devastate exposed coastlines.

Both the explosive phases can devastate areas within one to five km of the source and deposit tephra (of basaltic and country rock fragments) in a ring around the vent, up to hundreds of meters from the source.

- ***Tsunamis*** (waves) — when the eruption is in shallow water.
- ***Lava flows*** — which can travel several km from the vent.
- ***Lava fountaining*** — to and close to the vent.
- ***Hot airfall tephra***
- ***Ballistic ejecta*** (blocks, or 'bombs') — close to the vent.

2.5 Volcanic Legacy

Unusually difficult and potentially hazardous *ground conditions* exist in volcanic deposits, quite apart from the hazard stemming directly from future volcanic activity.

These ground conditions may be naturally unstable (as in the case of geothermal activity and active landslides). They may also be rendered unstable and dangerous by people's activity, such as the result of tunnelling or cutting through such deposits or the superposition of an extra load, or interference with the groundwater regime.

Experience with hydroelectric headrace canals, tunnels, powerstations and dams in the North Island volcanic terrain enables us to produce a list of such ground conditions which we may describe as *geotechnical hazards* of volcanic terrain. The term *volcanic legacy* is used to collectively identify these and to establish them as a category demanding our attention.

Extreme variability, rapid and irregular changes in physical properties, complex groundwater conditions and lack of exposure as a result of overlying tephra and surficial deposits make volcanic terrain unpredictable and difficult to assess.

We may therefore recognise:

- ***Geothermal activity*** - include hot water, steam and hot (but drier) ground.
- ***Hydrothermal explosions*** - as a result of natural or induced instability. Large explosion pits and craters may be created.
- ***Volcanic gases*** - not necessarily from active vents but in areas of geothermal activity, volcanic lakes and groundwater.
- ***Extreme lateral and vertical variability of deposits*** - such inhomogeneity can con-ribute to foundation failure, slope failures and downstream consequences.
- ***Slope movement*** - landslides (in a general sense).
- ***Collapsing soils*** - highly porous soils which can rapidly compress.
- ***Highly sensitive soils*** - quick clays, in which a sudden and drastic loss of strength can occur.
- ***Rapid slide-flows*** - these result from collapse and loss of strength in sensitive soils.
- ***Piping and tunnel-gullying*** - internal erosion in dispersible and readily entrained soils as a consequence of groundwater seepage pressures. Very rapid upward erosion and undermining of ground can lead to disastrous collapse of ground when large quantities of water are involved.
- ***Swelling ground*** - in hydrothermally altered materials, where smectite clays are present.
- ***Seismotectonic hazard*** - the hazard from earthquake and faulting can be locally very severe in active volcanic fault zones, such as the rift of the Taupo Volcanic Zone. Very shallow earthquakes may produce very severe amplification and ground failure (for example, liquefaction) in the extremely weak and unconsolidated saturated deposits of parts of the Taupo Volcanic Zone.

3. Quantification of Volcanic Hazard

Assessment of volcanic hazard rests heavily on information about the intervals between eruptions, the volume of material produced, the geographic extent of the material, and its make-up.

3.1 Risk Assessment

Intervals between eruptions (recurrence, periodicity). The basic principles of stratigraphy are fundamental. Determination of the *depositional sequence* of a pile of volcanic deposits from superposition and depositional relationships, combined with *age determinations*, enables an estimate of recurrence intervals to be established. Recurrence intervals permit an assessment of *probability*.

Magnitude of eruptions (volume of ejecta)

The volume of materials for an eruption can be estimated once the thickness and extent of a deposit, and its stratigraphic (and hence genetic) relationship to materials above and below, have been established.

Type of eruption (nature of the hazard)

From the morphology, mineralogy, geochemistry and physical content of the deposit, and its texture and fabric, the nature of the process of emplacement can be assessed.

Magnitude and type together establish grounds for considering the *consequence* of the eruption process. *Consequence* and *probability* (or Magnitude + Type X periodicity) provide an estimate of the potential risk. Risk varies with distance from source and the shape of risk zones varies with the nature of the eruption.

3.2 Risk assessment of active volcanism

This is dependent therefore upon:

- Stratigraphy
- Age dating
- Geologic mapping
- Geomorphology
- Geophysics
- Geochemistry

Radiometric dating (for instance radiocarbon dating and several other methods) in combination with *tephrochronology* (stratigraphy of air fall and pyroclastic deposits) and the stratigraphy and dating of marine sediments (containing air fall tephra) are of basic importance to establishing probabilities of risk from eruptions.

Once a picture is established of how activity at a volcano has varied throughout time, then average recurrence intervals and hence the probability aspect of risk can be assessed.

Likewise, the variation in volumes and nature enables an assessment of the variation of consequence with time to be established.

It becomes apparent that, in general, low consequence events have a high probability and high consequence events a low probability. However, uniformity should not be assumed and much of the data on which probability and consequence are determined is incomplete and tentative.

3.3 Categorisation of volcanic risk (active volcanism)

Probability

A distinction can be proposed between higher probability events (such as lahars and debris flows and tephra from andesite volcanoes) and lower probability events (such as rhyolitic ignimbrite eruptions). These probably represent extremes of probability in New Zealand, with our andesite volcanoes at the higher end of a scale and the rhyolitic ignimbrite at the lower end.

Consequence

Similarly, andesitic lahars (at the least the minor ones) and andesitic air fall tephra constitute a lower consequence category, compared to rhyolitic ignimbrites which would carry a far higher consequence. This distinction can be made, but the *ultimate consequences* depend upon what is at risk, and the ultimate predictable damage, loss, mortality or injury.

In this respect, the Auckland basalt volcanoes, although smaller in magnitude than the andesite volcanoes and apparently of lesser probability in terms of recurrence intervals, as far as we understand them, may well present a very much greater ultimate consequence.

3.4 Risk assessment of volcanic legacy (ground condition hazard)

The hazardous and difficult ground conditions of volcanic terrain are, mostly, amenable to risk assessment by geotechnical analysis. An example is the assessment of safety factors against failure of a slope in these materials, where the balance between forces resisting failure and those promoting failure is expressed as a safety factor. At a safety factor of 1, the slope is on the verge of failure, and above 1.0 assumes an increasing degree of stability: that is, the risk is greatly diminished.

This approach can be applied to the legacy type hazards of slope movement, collapsing soils, highly sensitive soils, slide-flows, piping and tunnel-gullying, and swelling ground.

However, the approach is dependent upon a chain of decisions in which the most critical function is the first: the recognition of the hazard. Hazardous ground conditions are not nearly as obvious as active volcanoes and many are entirely concealed. Asking the right questions so that problem identification — and hence hazard recognition — is achieved at the outset is crucial to an effective outcome.

Risk assessment follows a path of:

- Asking relevant questions
- Problem identification

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- Data collection
- Development of a tentative geomechanical site model

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- Plan to fill in the gaps

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- Determine a semi-quantitative engineering geological site model

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- Quantify the model by appropriate testing, *in situ* and laboratory

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- Analysis of all site data
- Answering of initial questions
- Solution of problems

Appropriate feedback checks are applied throughout this model, abbreviated a little after Stapledon (1976) and Bell and Pettinga (1984).

Inappropriate recognition or identification at the outset can lead to erroneous, if deceptively sophisticated and numerical, 'solutions' at the end. The development of a correct qualitative model is essential and rests heavily upon a thorough understanding of all the possibilities. Engineering geological models which are comprehensive are vital in this assessment.

4. Risk Communication

4.1 *Hazard maps* and risk maps are used widely to communicate the risk from active volcanism (for example, Crandell and Mullineaux, 1975 and 1978; Neall, 1982; Latter, 1987), and also to communicate the risk from hazardous ground conditions (Prebble, 1986).

The maps may be of either relative risk, of variation in risk or of probabilistic risk.

Relative risk maps indicate hazard zones, of different levels of risk, from one particular type of hazard.

Variation in risk indicates, on a map, hazards of different types and may include zoning one or more of the hazard types into subzones of relative risk.

A *probabilistic* risk map indicates not only the expected variation in risk, but provides an estimate of the chances of occurrence within a given time interval.

4.2 Risk communication, in the form of *public information* and *warning*, is also in use and is discussed more fully by Latter (1986). Examples include lahar warning systems on Mount Ruapehu.

4.3 *Monitoring and surveillance* of active volcanoes and volcanic fields is discussed more fully by authors such as Latter (1986) and is the subject of much current discussion.

Participants in the debate on monitoring and surveillance of the risk from natural hazards are referred to the work of Geology and Geophysics Division DSIR and the University of Auckland Geology Department (Drs Ian Smith and John Cassidy).

5. Risk to Engineering Facilities

Some data of relevance to assessing the potential damage to engineering structures and utilities was provided by the Mount St Helens andesitic volcanic eruption of May 18, 1980 (Schuster, 1983) and, to a lesser extent, from our own experience on the Tongariro Power Development (Paterson, 1980; Healy *et al.*, 1978).

Experience in Iceland, Sicily and Hawaii indicates the nature of the risk from basaltic volcanoes. Further experience, much of it very recent, comes from andesitic eruptions in Japan, Indonesia and the Philippines.

The risk is considerably focused as a result of the concentration of major engineering facilities (and population densities to some extent) along rivers which drain the active volcanoes.

Capital intensive structures such as bridges, viaducts, dams, powerstations, factories, mills, harbour complexes, irrigation canals and urban regions are sited on rivers out of functional need, geographic convenience or historic accident. Siting is determined not only by the water resource, but also by the need to find flat, arable land and proximity to transport nodes.

This places the engineering utilities immediately at risk from lahars, debris flows, floods, valley-fill ignimbrites and valley-channelled pyroclastic flows. Far-reaching effects of these hazards can cause damage at great distance from the source, well out of the zone of damage from some other eruption hazards (such as lava flows, base surge, ballistic ejecta, phreatomagmatic eruptions, fire-fountaining, thick air fall tephra and debris avalanche).

A chain of processes from source to coast can be observed, with near-vent sector collapse, debris avalanche and pyroclastic flow giving rise to debris flow, lahar, mud-flow downstream.

For instance, at Mount St Helens in May 1980 the sector collapse of the northern side of the volcano resulted in a 2.3 km^3 debris slide which degenerated into a hot debris avalanche that swept 24 km downstream. A directed blast devastated a much larger area, to a similar distance (more than 25 km from the volcano).

Similar devastation could be envisaged for New Zealand's andesitic volcanoes. Debris flows and mudflows could extend for nearly a further 100 km beyond the toe of the debris avalanche, in the main river valleys. Mudflows (lahars) would be generated in valleys other than the debris avalanche route as well — as a result of tephra mixing with water and snow.

5.1 Damage to Engineering Facilities

In the blast zone *(directed blast from sector collapse, or a more symmetrical blast from a large summit crater explosion).*

Sudden and total destruction of roads, bridges, buildings, harvesting facilities (timber harvesting), and recreational facilities. Larger facilities such as dams would be overwhelmed, if not destroyed.

From Schuster (1983) we may estimate total destruction for, say, 15 km. All soil and vegetation would be removed, pyroclastic flow temperatures of, say, 400°C and velocities of 100m/sec could be experienced. All life in this zone would be wiped out.

In the 'blown down' zone *(Schuster, 1983)*

Extending to, say, 22 km from the crater, forests would be killed and felled by the blast. For a further three or so kilometres a singe zone of burnt trees is likely.

In the debris avalanche zone

Up to a few km^3 of debris, averaging say 40 m thick but up to 200 m thick, would fill river valleys and adjacent topography, displacing lakes and rivers and creating new stream routes and ponding, for say 20 to 30 km.

Dams, reservoirs, power plants, roads, bridges, buildings and recreational facilities would be overrun and buried. Bridges and dams may be swept away. Reservoir water would be added to the flow of debris. Smaller buildings and facilities would be obliterated.

Flow-on effects of the debris avalanche

Until it is consolidated and bound by vegetation, the debris is a source of highly erodible sediment which could choke river channels, causing flooding and excessive sedimentation and flood plain aggradation well downstream. Bed load volumes, grade level, flood characteristics and suffocating sediment deposit could be drastically increased.

Side-effects of the debris avalanche

Damming of tributaries along the route of the debris flow could give rise to possible catastrophic overtopping, failure and breaching, resulting in further flooding and debris flows.

In the mud-flow zone (debris/mudflows)

Mudflows and giant log jams for some 30 to 60 km beyond the debris avalanche could bury and/or destroy roads and railways, and would probably destroy bridges. (In this context we are considering a much larger 'mudflow' — or debris flow — than the lahars experienced in recent decades from Mount Ruapehu).

Intakes for water supply, sewage and effluent disposal systems and oxidation ponds adjacent to waterways could be completely clogged with sediment and debris.

Overtopping of dams, and infilling of reservoirs is also possible in the mudflow zone.

Sedimentation further downstream

Raising of riverbed levels needs to be considered in relation to flood discharge, navigation channels, and water intakes (for industry, domestic, cooling systems).

The ash-fall zone

In the order of 500 million tonnes (or over one km^3 uncompacted) of airfall ash can be generated by an explosive andesitic eruption (Schuster, 1983). This may rise to a height of 20km in an eruption column.

An immediate hazard to air traffic is generated.

Another immediate effect is to paralyse ground transportation and to render temporarily inoperative sanitary-sewage systems, waste-water treatment plants, stormwater systems and open water supply systems.

Ash removal and disposal can take considerable time, involving much equipment and labour.

5.2 Potential damage from rhyolitic (ignimbrite) eruptions

These eruptions are several times to many tens of times greater in magnitude than the andesitic eruption of Mount St Helens. Therefore, the consequences are correspondingly potentially greater too.

5.3 Damage from basaltic volcanism

The damage zone is likely to be much smaller and more restricted than that discussed above (for andesite volcanoes). However, some different consequences are also to be expected, such as lava flows and fire fountaining.

Lava flows

Fluid, hot basaltic lava flows will create fires and overwhelm and destroy buildings and engineering facilities in their path. Ponding of lava will alter topography, overwhelming transportation routes, access corridors and facilities generally.

Blast zone

As a result of base surge and phreatomagmatic eruption, total destruction for a few kilometres around basaltic vents can be expected, followed swiftly by burial beneath ejecta.

6. Summary

- Volcanic risk arises from the effects of both:
  (a) Volcanic activity, and
  (b) Hazardous volcanic deposits and ground conditions.
- The risk is quantifiable through the application of basic geologic principles to volcanic deposits and the study of active volcanic phenomena. Hazardous ground conditions can be assessed using geomechanical procedures.
- Probability of volcanic operations can be assessed from recurrence intervals.
- Consequences can be assessed from basic geologic, geometric and physical data.
- Communication of the hazard includes hazard maps.
- Dependence upon the geologic record introduces uncertainties.
- Monitoring and surveillance are essential.

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AN ECONOMIC PERSPECTIVE ON RISK AND UNCERTAINTY OF INDUSTRIAL AND NATURAL HAZARDS

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1. Introduction

Industrial and natural hazards have economic implications. Some may arise as a result of economic decisions with regard to the establishment and operation of certain economic activities. Others may arise from different causes. In all cases the potential for the occurrence of industrial and natural hazards requires economic decision-makers to, firstly, assess the risks involved; and secondly, to adopt a strategy for the management of the risks so perceived.

The definitions of *risk* and *hazard* proposed by John Gardenier (Briefing Paper: General Concepts of Risk, April 1991) are accepted in this paper, namely:

Risk is the probability of a specified loss or harm (the probability component of risk);

Hazard is the potential loss that can cause human, social, environmental or economic harm (the consequence component of risk).

The chief burden of this paper will be to examine the distinction between risk and uncertainty introduced into economic analysis by F.H. Knight (1921). Is it possible to identify potential events to which no probability can be attached in any meaningful way, and which yet may have a consequence component? If this is so, then how would one manage such consequences?

2. The Distinction Between Risk and Uncertainty

Knight (1921) and Shackle (1955) have introduced a sharp distinction between risk and uncertainty. Knight discusses three types of 'probability' situations:

(i) *A priori* probability, such as the probability of getting heads or tails when tossing a coin;

(ii) Statistical probability, where from past instances one can infer a probability, such as the risk of fire or death.

(iii) Estimates where one has no valid basis of any kind for classifying instances.

Since Knight styles the third situation 'uncertainty', it would be better to talk about three 'possibility' situations. This allows us to add a fourth category which can be described as follows:

(iv) Situations where we can surmise that certain events might occur, without being able to assign any probabilities to them.

Category (iv) is akin to a situation of a-certainty, an absence of certainty, rather than the third possibility in which decision-takers are essentially ignorant.

Another way of characterising these four cases is by the type of causality involved.

In the first case, causality is mechanical. The environment is controlled. Once A occurs one can predict with certainty the occurrence of B. A business example would be a sawmill with wrongly set tolerances. One can then predict that the wood sawn will not comply with the specifications required.

In the second case, one can only predict that certain events will occur on the basis of actuarial or similar calculations. One may not know, however, how the causality actually works. An accident, for example, may lead to a fire. Prediction is dependent upon the availability and analysis of past records.

In the third case, the possible causes are known, but the potential effects (consequences) are unknown and cannot be inferred from past instances. The effects depend upon the state of the system as a whole. There is no mechanical relationship between cause and effect.

In the fourth case, one does not know what the causes of certain events might be. One may know that certain processes or combinations of events could entail the possibility of disasters, but the nature of the causal relationships is unknown.

The important point is that uncertainties and a-certainties are not risks. They can have no probability distribution. If they did, they would be known and hence would be insurable through systems of risk-pooling (insurance) or future markets. This does not necessarily mean that there cannot be markets in uncertainties. This depends on whether there are sufficient actors prepared to take bets on one side and sufficient to take another view.

A practical example of risk might be that an examination of weather patterns in a certain area over a long period of time reveals the occurrence of droughts or floods every three or four years on average; a business planner can therefore calculate a probability of drought or flood. This is an example of the second probability case above, in which risk can be anticipated and hedged in various ways.

An example of uncertainty is when a farmer contemplates an investment in cattle, using whatever probabilities he or she is able to derive, but realising that foot and mouth disease might strike, a supercow might be bred in Europe, or that extreme droughts or war overseas could bring price increases far beyond any level reached in the past. Such potential surprises (Shackle, 1955:31) can be surmised, but they cannot be reasonably foreseen to occur with a certain degree of probability.

Gardenier's distinction between risk and hazard is interesting inasmuch as it allows for cases where the probability of particular events could be established (say, mishaps with nuclear power plants), but where the consequences are completely uncertain (would the initial mishap escalate to the size of the Chernobyl disaster of 1986 or be confined to a minor local emission of radiation?).

It is important to note that there are various ways of dealing with uncertainty and its potential impact. Knight, for example, discusses how a business might be organised to cope with uncertainty. A business set up as a limited liability company might better cope with the effects of uncertainty than a single partnership. Specialisation in certain business activities is another ploy. Uncertainty can be managed to an extent.

In the case of a nuclear power plant accident, the uncertainty of the consequent component of risk would be managed by designing power plants which include as many safety devices (such as container vessels) as possible. Even this, however, might be insufficient to prevent a large disaster, as the behaviour of operators in such plants during a mishap has often aggravated the consequences of an initial mistake. Unpredictable behaviour of operators in stress situations is a psychological uncertainty.

Van Dijk and Rosing (1989) have analysed the possible effects of storing 75 million m^3 of natural gas in liquid form in a peak-shaving installation close to Rotterdam (that is, close to major residential and industrial areas). This plant was built there to save on transport costs during peak usage times. The key hazard is the possibility of a gas explosion leading to a fireball. They demonstrate the enormous uncertainty of the extent and ferocity of such a fireball. Not only could large cities be hit, but also large petrochemical plants. Fires at the latter could also trigger explosions in the peak-shaving installation. The actual financial saving gained by this installation was the very modest sum of Fl 90 million. The authors note that available studies of the probability of a calamity differed by a factor of 10^{-8}. In this case, one should call it an uncertainty. They conclude — correctly, in my opinion — that a political decision should have been made about the acceptance of the possibility of major accidents. Moreover, various alternatives were available, such as shutting down major users of natural gas during a cold spell and forcing them to switch to alternative fuels.

Knight (1921) indicated the need for political decisions to deal with uncertainty:

> *It would doubtless be possible to use all the resources of society with more or less effect in reducing uncertainty, leaving none for any other use. It is a question of how far to go. The question is complicated by the fact that the use of resources in reducing uncertainty is an operation attended with the greatest uncertainty of all.*
>
> \- Knight (1921:348)

For the sake of convenience, the rest of this paper takes *uncertainty* and *a-certainty* together as one concept to be named 'uncertainty'. The distinction becomes important, however, when the management of 'certainty' is discussed.

3. Uncertainty More Prevalent than Risk in Economic Decision-making

In order to derive reliable probabilities from past records, the law of large numbers should apply. In most cases, especially when technology changes continuously and natural hazards such as major earthquakes, devastating cyclones and large volcanic eruptions are very much discrete events, this law is rarely satisfied. For example, in normal circumstances the number of gas molecules in 1 cm^3 is 10^{-19}. The behaviour of these molecules can be determined close to exactly. By contrast, the number of economic activity units in a country is usually well below such a quantity. In New Zealand, the total number of enterprises was merely 150,120 (about 10^{-5}) in February 1990. Many of these enterprises, however, would be subject to the control of single groups or influenced by a few key financial institutions.

Moreover, economic decision-makers often determine their actions in response to actual or perceived actions of other decision-makers. This introduces a strong element of indeterminacy into the behaviour of economic variables. Even when the underlying technical data — for example, the occurrence of fires — follow distinct probability distributions, the corresponding premiums set by insurance companies may vary depending on the market structure for insuring fire risks (monopoly, oligopoly, perfect competition), the state of the business cycle (in a boom premiums rise; in a recession premiums fall, although there are instances where adverse events increase during a recession — arson , for example).

Uncertainty about the duration of life is one reason why economic actors undervalue their future needs, according to Bohm-Bawerk (quoted by Hennipman, 1945:309-310), the other causes being their limited idea of future needs, and a proclivity of the human will to be satisfied with less gain now rather than with more in future. In addition, knowledge of future needs can only be very approximate. Finally, the economic actors are liable to make mistakes in their estimates.

Thus, discussing the prospective yield of investment, Keynes wrote:

> *Our knowledge of the factors which will govern the yield of an investment some years hence is usually very slight and often negligible. If we speak frankly, we have to admit that our basis of knowledge for estimating the yield ten years hence of a railway, a copper mine, a textile factory, the goodwill of a patent medicine, an Atlantic liner, a building in the City of London, amounts to little and sometimes to nothing; or even five years hence.*
>
> \- Keynes (1936:149-150)

Such uncertainty is the reason why 'animal spirits' are important when it comes to making decisions about capital investment.

Financial institutions which have to risk their capital on lending to business enterprises will, therefore, be unable to use probabilities to determine how much to lend to particular firms, industries or individuals. They will aim to limit their exposures, to examine the credit-worthiness of their borrowers, to assess the state of industries, to gauge movements in macro-economic policy and in financial markets around the globe.

Information is the key word for bankers as they try to manage in a very uncertain world.

4. Risks can be Priced or Hedged

Since, in principle, risks are calculable — being associated with events which occur on the basis of known probabilities derived from occurrences in the past or in analogous circumstances — they can be insured against or hedged through futures markets, or by suitable diversification policies.

By contrast, it is impossible to conceive of a market for uncertainty. Uncertain events are unique events, which we may be able to surmise, but which we cannot predict. They reflect our ignorance of the causality of the environment.

This does not mean to say that insurers will never refrain from offering insurance against uncertain events. Within the field of marine insurance, for instance, there are mechanisms for insuring against the uncertainty of war during transport over sea. To this effect, the major insurers involved assess continuously the state of security in various danger spots on the basis of information they are able to glean. They then decide whether it is possible to insure cargoes and advise the premium level accordingly. They may also decide that, because certain areas are too dangerous, no insurance should be offered. The important point is that through a process of information-gathering and expert assessment, an uncertainty is transformed into an insurable risk.

Even if insurance companies were prepared to insure truly uncertain events (perhaps because they believe it is possible to bet against them), they might not be able to honour their commitment in the event of a disaster.

In general, however, private insurance for uncertain events is unlikely to be available from private companies. Moreover, in perfect competition, the cost structure of producers cannot incorporate the cost of such insurance, unless all producers are insured.

In the face of uncertainty, producers may not undertake the same volume of investment as they would in the absence of uncertainty. If some way could be found to manage or alleviate uncertainty, investment would be increased.

From the point of view of individual producers, the risks for which they are insured are, in fact, uncertainties for their own business. Business managers must decide whether they accept an uncertainty and gamble on it not occurring, or whether they adopt their own management system for that uncertainty (for instance, by shipping a certain amount of cargo in many small ships instead of in one big ship), or have the uncertainty transformed into a risk via the insurance market.

Within the insurance industry similar management strategies exist. If the risks to be insured are too large given the amount of financial reserves available, they may use the re-insurance market to cover the risk. In this case, a larger pool of funds is available to cover that risk.

Since prices (insurance premiums) are the subject of legally binding contracts, it is essential that insurance companies are able to assess the probability and consequence components of risks as accurately as possible.

5. Some Sources of Uncertainty

Uncertainty should not be equated with ignorance. Decision-makers usually realise that the future will never be an exact replay of the past. Even the patterns of the past might not obtain during the future. On the other hand, if we were completely ignorant of the future, making choices would be meaningless. Changes made in the past have a momentum. Human nature has not changed for centuries. Faced with uncertainty, it makes sense to strive for a prognosis, a task facilitated by carrying out a systematic analysis of the sources of uncertainty in a particular environment or over a certain period of time.

Uncertainty springs from various sources. Without being exhaustive, the following categories of uncertainty appear to be important for industrial and natural events:

5.1 Belief Systems

In Western societies there is a strong belief that what can be made should be made and that ethical, political and other implications of new technologies should take second place. The danger is always that new technologies are introduced without a detailed examination of all possible effects.

Reactions against this 'technism' have taken the form of environmental pressure and lobby groups, to the extent that they have created uncertainties about the possibility of development..

Changes in belief and value systems are very important from the point of view of what Gardenier (1991) has called *risk perception*. Greater environmental awareness, for instance, might have stopped the construction of the peak-shave storage facility of liquid natural gas close to Rotterdam.

5.2 Political/Legal Changes

As noted above, many uncertainties require political decisions. Since political parties differ and different political parties form governments from time to time, the political management of uncertainties changes. Similarly, political changes can themselves cause uncertainties. When a government insists on greater safety in workplaces, this has consequences for the types and costs of technology to be employed there.

The view of recent National and Labour Governments that the State should not be involved in the private sector and should not, for instance, plan for new sources of energy supply, may have increased uncertainty.

If the shortage of energy due to the depletion of the Maui gas field in 2005-2009 is not be met from new indigenous resources, then natural gas might have to be imported. Given New Zealand's distance from overseas supplies, this might necessitate the construction of a peak-shave installation.

Countries which are less sensitive to environmental concerns than others may attract more hazardous and more polluting industries.

Regulatory uncertainties (emission standards, approvals for new drugs and hormones) and patent problems (intellectual property rights) should also be mentioned here.

5.3 Social Changes

Increased drug usage could enhance the danger of industrial accidents.

5.4 Advances in Science and Technology

New technologies emerge all the time, even though fundamental breakthroughs are comparatively rare.

The introduction of superconductivity, for instance, would have impacts on industrial location, transport, production costs and so on, in unforeseeable ways.

In the absence of sure knowledge of the processes of innovation, strategic decisions on business planning must be made under uncertainty. Management will have to devise these strategies in such a way that options remain open. As knowledge improves, better informed decisions can be made.

New technologies create the possibility of new risks and hazards. While efforts can be made to assess these in advance, it is exceedingly difficult to calculate probabilities.

Interaction between new and existing technologies could be another source of uncertainty. Similarly, the degree to which an economy is undergoing processes of capital deepening or widening. In the former case, the process becomes increasingly complex, involving more stages of production between raw materials and final products. In the latter, the ratios of labour to capital remain the same, but more similar activities are being added. Clearly, when there is capital deepening, the possibility of mishaps occurring tends to increase. Interdependencies between producers also rise and this, in itself, compounds the threat of uncertainty with regard to the occurrence of industrial risks and hazards.

5.5 Psychological/Emotional Aspects

Reactions of operators of processes and equipment, especially programmed equipment, to unforeseen events can be a source of trouble. For instance, software designed by a group of programmers tends to become the 'property' of those programmers. Even when they document their program fully, it seems likely that others using the programs may not feel that they fully understand the system under unknown circumstances. In difficult circumstances, this could lead to wrong reactions. Similarly, stress could play a role in the occurrence of accidents.

5.6 Perceptions of Hazards

As the example of the peak-shave storage plant for liquid natural gas in Rotterdam indicates, perceptions of major risks may be very deficient or may be overruled by narrow economic calculations, especially if expert opinions on the severity of possible mishaps differ widely. Recognition of an uncertainty in this case might have prevented the insurance company from insuring the plant and led to the implementation of a different alternative. If perceptions of possible, though difficult to quantify hazards, were correct then the uncertainties involved would be managed differently. The role of insurance companies in this connection is very interesting. As mentioned above, they might sometimes be tempted to gamble on outcomes.

The environmental movement is having a strong impact on how potential accidents and hazards are being perceived, with consequent effects on the shape and type of new technologies, the rate of diffusion of innovations and the location of industry (Green and Yoxen, 1990).

5.7 Biotic Changes

Biological uncertainties have come to the fore in recent years with the development of bioengineering. The Administrative Supreme Court in Hesse ruled recently that the safety of producing genetically engineered human insulin, for which Hoechst wanted to build a factory, could not be assessed on a legal basis and therefore halted the construction plans (Green and Yoxen, 1990:480).

Uncertainty about the safety of biotechnological processes, whether true in fact or not, can have an important bearing on innovation and the location of investment.

5.8 Changes in Climate/Biosphere

Plants designed to operate in certain climatic conditions could face problems if climatic changes moved the actual atmospheric conditions to levels different from those assumed by the designers.

Sustained emission of Co_2 is bound to have some effect on climates, but the precise extent and nature of these effects is unknown. Perhaps engineers should recognise this uncertainty by increasing tolerances.

Public awareness of the effects of greenhouse gases, including sulphuric acid (acid rain), will lead to requirements to eliminate or significantly reduce emission of such gases.

Development of new chemical products may involve unknown effects which can only be approximated. Design of production facilities should allow for such uncertainty. If residual doubts remain, they should be spelled out. An interesting example is the development of planes that are completely controlled by computers (Airbus).

Responsibility for the design of appropriate software was given by Airbus to two distinct independently operating programming/computer firms, and the planes use both systems. Unknown physical/aerodynamic effects that could not be properly handled by one system could be handled by the other. There is no guarantee, however, that all possibilities will have been foreseen by both systems. The resulting residual uncertainty has obviously been judged acceptable, compared with control systems requiring greater human input.

5.9 Geological Changes (volcanoes, earthquakes)

Volcanic eruption and major earthquakes are always a possibility, but cannot be predicted with a degree of accuracy helpful to business planning. The Government has assumed some responsibility in this regard through the Earthquake and War Damage Commission, Civil Defence, and through scientific monitoring and research.

A plane flying through a volcanic dustcloud that caused all its engines to shut down is an example of this type of uncertainty. It is a major compliment that the engines could be re-started in time to prevent a disaster, although this is also an uncertainty.

5.10 Economic Changes

A prolonged recession or a strong boom is capable of influencing not only the rate of technical change, with consequent effects on the interdependencies between industries, but possibly also the tolerances with which new equipment are being designed and the time during which equipment and plant are being run.

6. Time

Basic attitudes to time cut across the discussion of the various sources of uncertainty.

In economics, time is expressed in terms of the relationship between the present and the future, as reflected in interest rates.

Communities with a very high value for the future and a correspondingly low esteem for the present, would invest much more longer-term than those with the opposite proclivity. This will have effects on the rate and type of technological development. A community that thinks in the longer-term might not choose a high degree of economic obsolescence. Buildings, for instance, would be constructed to last for 200-300 years, instead of the now customary 50-60 years. As more time would be spent on the construction and testing of new technologies, the probability of risks and the consequent components of hazards would change. However, there is a danger that a longer-term type of community would lock into new technologies for too great a period of time.

Conclusions

Some implications of this analysis are that deliberate attempts to distinguish between uncertainties and risks, and then to focus on ways of covering risks and managing uncertainties, will lead to better decisions. A follow-up to this paper would be an examination of decision-making under uncertainty.

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A TOXICOLOGIST'S PERSPECTIVE

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1. Introduction

Toxicology is a relatively new scientific field that developed this century as a result of the growth of chemical innovation in the production of pharmaceutical substances, agrichemicals and industrial materials.

Because of its relative youth, toxicology as a field has not yet developed universally applied methods of quantitative risk assessment. A number of different approaches are applied by different countries or economic groupings. Indeed, as we shall see from some examples, there can be diverse results even using similar methods, because of the relatively large uncertainties associated with the approach to risk assessment in toxicology.

In this discussion, I will focus on examples drawn from environmental chemical issues, and will restrict the scope to consideration of risks of chemicals to human health.

2. Risk Quantification

2.1 The Basics

When considering adverse effects of chemicals in the environment, the toxicologist is immediately faced with a dilemma. It is not possible to carry out experimentation on humans, but the toxicity of the chemical in a human is precisely what you are trying to determine.

The problem for environmental chemicals is even greater than for pharmaceutical substances. For these latter substances there are potential benefits to those exposed and, after suitable preliminary investigations, clinical trials can be carried out ethically.

The assessment of environmental chemicals relies, therefore, on two main sources of information:

(1) animal and *in vitro* test systems combined with appropriate toxicological expertise to estimate risk to human health of proposed use of the chemical;

(2) epidemiological investigations which detect incidence of diseases in the population and attempt to relate these to possible environmental/lifestyle factors.

2.2 Toxicology Investigations

2.2.1 *General Toxicology*

The assessment procedure for a new chemical depends on the anticipated quantity of the material to be used and the extent of human exposure. Thus, a food additive and a pesticide likely to give rise to food residues would be very rigorously assessed, due to likely widespread exposure of a large proportion of the population; while a specialised industrial intermediate likely to be used by a small number of factories in an enclosed process would undergo less testing unless production quantities and exposures were projected to expand greatly.

Table 1 lists the basic types of tests that are commonly used in toxicology [1]. This list is not exhaustive, but gives some idea of the wide range of studies needed, and the length of time involved in the assessment process.

Table 1 - TOXICOLOGY TESTS

STUDY TYPE	ANIMAL	DURATION	AIM
acute	rodents	short-term	general tox.
sub-acute	rodents	medium-term	general tox. (3 months)
reproductive	rats/rabbits	medium/long (months/years)	reproductive effects
chronic	rodents/dogs	1-2 years	general tox. cancer
mutagenicity	micro-organisms	short (weeks)	genetic tox.
	rodents	medium-term	genetic tox.
	mammalian cells	short-term	genetic tox.

The most generally applicable method of quantitative risk assessment is based on thresholds for general toxic effects determined in chronic or sub-chronic toxicity tests. For toxicological outcomes (other than cancer — see Section below) it is assumed that the seriousness of toxicological assault is determined by the dosage of the chemical. To use the adage of Paracelsus: "The dose makes the poison". It is assumed, therefore, that there will be a dose level at which no toxic effect occurs[2]. This gives rise to the concept of a *no observed effect level* (NOEL) in the animal test[3].

Any animal testing regime will employ untreated controls and, usually, three dose groups. Dose levels are established with the aim of seeing toxicity in one or more of the highest dose groups, and none in at least one of the lower treated groups. The highest dose level with no observed effect on the animals is the NOEL. This is determined by ensuring that the toxic effects seen at higher dose levels are absent. These may be minor changes, such as reduced body weight, gastric upsets, patchy fur, or changed blood biochemistry. In special studies, the NOEL may be based on the absence of more severe adverse effects, such as reduced fertility or foetal loss.

Tests must be carried out on a range of rodent or mammalian species, and the lowest NOEL seen in any of these studies is used as the basis for determining the acceptable daily intake (ADI) in humans. (Thus the ADI is based on the most sensitive model species, unless there are good scientific reasons relating to metabolic pathways which indicate that species is not an appropriate model for humans).

The most commonly used safety factor is a 100, although values may range from 10 to 5000, depending on the type of toxic effect seen and the type of study in which the NOEL was determined. The 100 safety factor allows one order of magnitude (factor of 10) to allow for uncertainty when extrapolating the results from animal tests to humans, and another order of magnitude to allow for variability (different ages, health status — see Appendix B) within the human population. The safety factor may be greater if the toxicity findings are of particular concern (for example, reproductive effects), or if sub-acute studies were used in the determination. A higher safety factor is also used if the toxicology study in which the NOEL was determined had minor deficiencies (if there are major deficiencies, the study would be disregarded).

The result is an ADI in humans. Essentially, this is a conservatively estimated NOEL for the human — it might be 0.001mg/kg body weight/day. This level represents the intake of the compound it is believed the human population as a whole may consume day after day throughout their life without adverse effect.

When comparing intake levels against an ADI it will be the average intake that is of prime relevance. This is an important point in relation to different age groups, because on an intake per body weight basis, young people generally receive a higher intake. This is also true of young animals in studies, who consume higher quantities of food, but this is an area which frequently raises concerns (such as with the Alar analysis in the USA in the last few years). Large excesses should be evaluated in relation to the toxicology data by suitably qualified staff if excesses occur. Points relating to population diversity are covered further in Appendix B.

2.2.2 *Quantitative Risk Determination for Carcinogens*

The second aspect of toxicological risk evaluation that I wish to discuss is the determination of risk from long-term toxic effects, particularly cancer. It is in this area that quantitative risk assessment in toxicology is most controversial.

With a chemical that causes cancer the NOEL concept discussed above does not generally apply. If a rat study gives rise to an increased number of cancers in the animals, it is important to realise that this is a statistical process. The number of cancers increases with increasing dose, but it is very unlikely that all the rats, even in the highest dose level, will get cancer. In the animal study a low dose group may not show any increase in the number of cancers, but this may be only because the proportion of animals expected to get cancer is so low that in a feasible study involving perhaps 100 animals the researcher is unlikely to see any cancers. It can reasonably be argued, therefore, that this low dose level does *not* represent a NOEL in the sense used for other toxic effects, but that in reality it represents the limit of sensitivity of the study. The use of a safety factor based on the NOEL is, therefore, not generally appropriate for carcinogens.

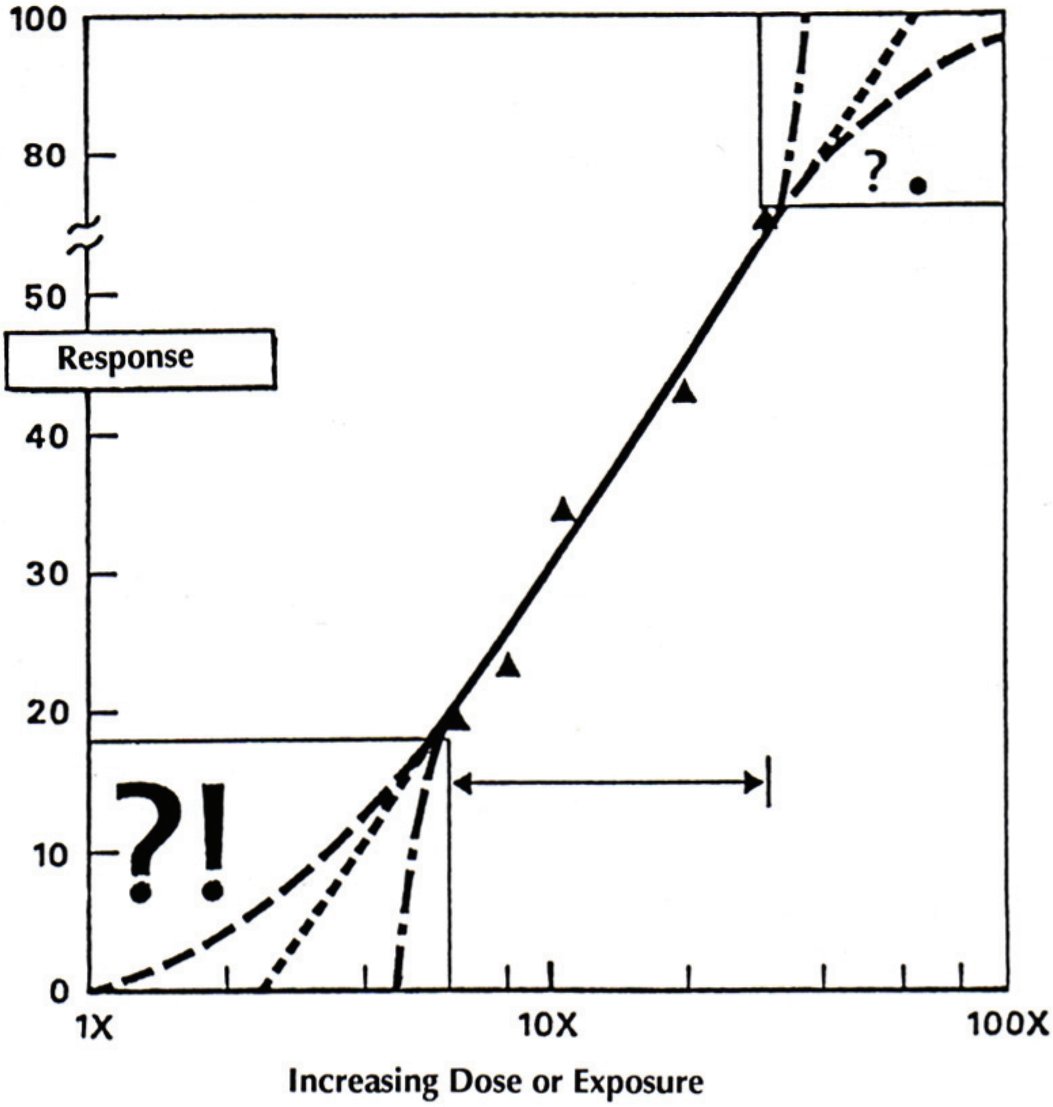
At this point it is appropriate to point out that this theory of carcinogenicity is considered particularly applicable for chemical carcinogens which are mutagenic, since this indicates that they act by damaging a cell's genetic material. Carcinogens may also act via cellular receptors. An extreme position argues that a mutagenic event in a single cell could progress to become a tumour.

This suggests there may be no safe dose for a carcinogen, and has given rise to a lot of discussion and some controversy[4]. It was also the basis for the so-called Delaney Amendment in the US Food and Drug Act, which stated that no additive could be used if it gave rise to cancer in any laboratory test.

How then are we to determine an ADI? Indeed, should we allow exposure to such substances at all? In the real world we have little alternative, since some naturally occurring materials, and even foods and essential vitamins, have been found to be associated with increases in cancer in animal test systems. The Delaney approach was introduced when the widespread nature of chemical carcinogenesis was not recognised, and before the variety of theories for carcinogenicity were developed.

The key issue becomes how to extrapolate the dose/response relationships observed at relatively high dose levels in the test species back to the low levels to which humans are likely to be exposed, day to day.

Figure 1 - DOSE-RESPONSE RELATIONSHIP



Simulated percent of individuals responding adversely to the logarithm of selected doses. Measurable responses are represented by triangles. The sigmoid curve (– – –) represents a population described by normal distribution; in theory the percent responding never reaches zero on the low end or 100 percent on the high end. The other curves (--- and –·–·–) represent a threshold for the response. The boxed in portions represent regions in which prediction of incidence depends on stochastic, statistical projection.

Figure 1 elegantly illustrates the dilemma before us[4]. We only have a dose response relationship for a small range of doses. We cannot go lower in a carcinogenicity test, as this would need prohibitively large numbers of animals and cannot be sustained on cost or ethical grounds. One low dose experiment was carried out in the USA involving 24,000 animals. It showed the importance of maintaining animals late into the lifetime, otherwise carcinogenic findings can be missed, but it did not resolve the shape of the curve at low doses.

The decision of how to extrapolate the dose curve back to the low dose rates that humans are exposed to is largely arbitrary and relates to one's preferred biochemical theory for carcinogenicity. Some favour a threshold, others a linear extrapolation. Then there is the question of a single hit, multistage or multiple hit model. (The single hit assumes a single cell could be transformed by a single molecule and progress to cancer. The multiple stage assumes there needs to be several transformation stages for this to progress to cancer. The multiple hit model assumes that a critical number of cells need to be transformed before a tumour develops)[5,6].

Another decision also needs to be made. What is an 'acceptable level' of risk? Any of these models involves extrapolation down to predict what dose would give a particular risk in the human. In the USA an increased risk of 1 in 1,000,000 has generally been used, whereas the WHO Guidelines for Drinking Water use 1 in 100,000[7]. These sound very low risks, but when you consider the size of the human population exposed, even low risks would represent a significant number of people affected.

Table 2[5] with calculated risk estimates for the proven animal carcinogen dimethynitrosamine (DMNA), gives an example of the results obtained by using different extrapolation models and risk levels to estimate a virtually safe dose (VSD). (Note these calculations give a VSD rather than an ADI for humans).

Perhaps the most significant thing to note is the wide range of risk estimates that result from the use of different model systems. Further examples are provided in Appendix A.

Table 2 - RISK ESTIMATED FOR DMNA WITH DIFFERENT MODELS
(Taken from Table 6 Ref. 5)

MODEL	1 in 10 EXP4	1 In 10 EXP6	1 in 10 EXP8
ONE HIT	3.1*10 EXP-3	3.1*10 EXP-5	3.1*10 EXP-7
MULTISTAGE	5.7*10 EXP-3	5.7*10 EXP-5	5.7*10 EXP-9
MULTIHIT	1.3*10 EXP-1	1.3*10 EXP-2	1.3*10 EXP-3
WEIBULL	4.6*10 EXP-2	4.6*10 EXP-3	4.6*10 EXP-5

2.3 Epidemiology

Epidemiological investigations attempt to identify causal factors for diseases in the human population. For the purposes of this paper, studies which relate disease to possible environmental/lifestyle factors are of interest. The question frequently arises as to whether the associations found are casual in nature.

The studies can be done in a variety of ways, but they all require key features: a defined population that is exposed; a defined control group with no or less severe exposure; information on the mortality or morbidity of these populations, and on their levels of exposure to both the hypothesized causal factors and possible confounding causes for the diseases under investigation.

These studies are extremely time-consuming, expensive and difficult to perform. There are difficulties associated with retrospective studies which are more common but less powerful, and prospective studies which are preferable, but take much longer and are more expensive.

In relation to carcinogenic outcomes it is important to realise that cancer induction has a latency period. Thus a carcinogenic exposure may only result in an increase in cancer incidence 10-20 years later. Unless the individuals are followed for this length of time or were exposed that long ago, the results must be considered inconclusive. In this context, prospective studies relating to carcinogenic outcomes, therefore raise the problem that many more people may be exposed before a positive finding is known and confirmed.

It is important to remember that despite the statistical manipulation needed in epidemiological studies, they are essential if we are to find definitive answers in relation to human exposures. These studies are really the only means to find out whether or not chemicals in the environment (including food and water) are associated with adverse human health effects. Otherwise we are limited to extrapolating from animal results, which ultimately cannot give the final answer. Animal test systems are only ever going to be a model.

Most importantly, it is inappropriate to say we are unaware of any increase in a particular disease as a result of exposure to a chemical, if properly conducted epidemiological studies have not been done to find such an increase. (The increase would have to be enormous or the disease extremely unusual if it was to be identified without such studies being necessary.) On the other hand, to say that the rate of cancer in the population has increased on the basis of the raw data before determining the age/sex adjusted rate and excluding known confounding factors, particularly lifestyle factors such as smoking, is just as unscientific.

3. Risk Mapping

Risk mapping is most relevant to point sources, such as chimneys or factories. It is less likely to be relevant to toxicological hazards which arise through water supplies or food sources. There is a place, however, for estimating the likely risk to different sectors of the population due to different exposures and susceptibilities.

4. Risk Perception

Commentators have often reflected on the risks associated with various occupations, and the widespread discrepancy between what the public *perceives* as being high risk and the *actual* level of risk. The importance of free choice frequently comes into the equation too, with the public or workers unwilling to accept high risks involuntarily, and particularly unknowingly.

Many people have a great fear of chemicals because they do not understand them, and because harmful effects could be insidious and not recognised, in contrast to explosive or flammability risks where incidents are clearly seen when they occur. Sometimes chemical risks relate to incidents (for example, spillages and fires), but more commonly they relate to low residues in food, water, or the environment from drift or background concentrations in the food chain worldwide. These are seen as particularly pernicious. Another problem relates to the perception of what the small numbers associated with risks or chemical analyses actually mean in real terms.

Toxicology, being a relatively new and mysterious field, suffers considerably from public perception of risk levels. Toxicological issues are frequently given such high public profile that they become political, and then a decision may be based on emotion rather than being made on a scientific basis.

5. Risk Criteria

Key documents are the *WHO Environmental Health Criteria,* in particular the volume providing guiding principals for assessment of toxicological data [3].

The *WHO Guidelines for Drinking Water Quality* also provide useful consideration of risk criteria, particularly in relation to carcinogenic risks, and set a 1 in 100,000 increased risk of cancer as the basis of their values[7].

Conclusions

In the toxicology area, the most important thing to remember is the science behind the process. We must carry out the appropriate animal and *in vitro* tests, determine as much as we can about the mechanism of toxicity or carcinogenicity and then, after considering the relevance of the results to human exposures, do our risk assessment. It is no good starting with poor data, using an inappropriate model, and then doing lots of calculations and calling that quantitative risk assessment. The final answer will only be as good as the data and interpretation on which it is based.

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7. WHO, *Guidelines for Drinking-Water Quality*, Vols 1-3, Geneva, 1985.
8. *A Survey of Some New Zealand Retail Milk Supplies for the Presence of Dioxin*, March-April, 1989, Department of Health, Wellington, May 1989 (see Appendix A).

APPENDIX A

Examples

1. Dioxin

To give a topical example of how estimates of carcinogenic risk can give rise to wide-ranging risk assessments, we can look to the dioxins .

The risk presented by members of the dioxin family are assessed in terms of their toxic equivalent concentrations, which relates to the estimated equivalent quantity of the substance 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD) present.

TCDD causes cancer at extraordinarily low intake levels in rats -1 ng/kg of body weight per day (a nanogram is a thousand-millionth of a gram). However, TCDD is not mutagenic, so it could be argued that there should be a threshold for carcinogenicity in this instance.

A table setting out the various standards for dioxin exposure taken from Appendix 1 of Reference 8 is reproduced below.

The New Zealand Department of Health has adopted the Nordic Council Permissible Weekly Intake (PWI). This is based on a threshold approach with a NOEL of ng/kg of body weight and a 200-fold safety factor, and is equivalent to a permissible daily intake of 5pg/kg of body weight per day in the human. (A picogram is a million millionth of a gram). The Department of Health took the decision to be somewhat conservative and use twice the safety factor used for pesticide ADIs, because of the uncertainty associated with the carcinogenic effect of dioxin and the high public perception of dioxin risk.

In the USA, authorities used a linear risk extrapolation calculation to determine a virtually safe dose (VSD). Three separate federal agencies did their own estimates with different models, so three separate VSD estimates have resulted. This highlights the variability associated with risk assessment in the toxicology field.

2. Chloroform

In New Zealand, the Department of Health has not developed its assessments to the point where quantitative risk assessments are done routinely. This is due, in part, to the small number of toxicologists that we have in this country, and also because standards have usually been determined using a NOEL approach.

One example where standards have been based on quantitative risk assessments is the setting of drinking water standards, because we have based our standards on the WHO guidelines[7], which are based on a 1 in 100,000 increased lifetime risk of developing cancer. One example of a standard set in this way is the 30ppm standard for chloroform.

It is interesting that the water standard was not based on epidemiological results, even though some evidence was suggestive of an association between exposure to chlorinated water supplies and increased bladder cancer rates[7]. It will be interesting to see whether the standard for chloroform is changed during the current review of WHO guidelines.

Table A1 - STANDARDS FOR DIOXIN EXPOSURE

COUNTRY AND SOURCE	TYPE OF STANDARD	RISK LEVEL	STANDARD (PG/KG BODY WEIGHT/DAY)
USA EPA	VSD	1 in 10^6	0.0064
USA FDA	VSD	1 in 10^6	0.0576
USA CDC	VSD	1 in 10^6	0.0276
Canada	MADI	N/A	10
Federal Republic of Germany	MADI	N/A	10
Netherlands	ADI	N/A	4
Switzerland	MADI	N/A	10
Nordic Council	PWI	N/A	35 (weekly)

VSD = Virtually Safe Dose

MADI = Maximum Allowable Daily Intake

ADI = Allowable Daily Intake

PWI = Permissible Weekly Intake

N/A = Not Applicable

EPA = Environmental Protection Agency

FDA = Food & Drug Administration

CDC = Centre for Disease Control

APPENDIX B

Notes

1. Population Diversity

Human population diversity is well-documented. Particular genetic groupings of the human species have metabolic differences that become apparent during drug investigations. Furthermore, aside from genetic differences, there are environmental factors that can make an enormous difference. For example, smokers are exposed to a large number of toxic materials and this alters their metabolism of other chemicals. Similarly, those who suffer from particular illnesses (or have done so in the past) may differ metabolically, due either to the illness itself or to the long-term use of medication.

2. Carcinogenicity : One Hit or Multiple Hit?

There are convincing points to be made on both sides of the argument. The one hit model is probably most appropriate for radiation risks, but even then there are repair mechanisms in cells for dealing with DNA damage. In the case of chemical assaults, some carcinogens are likely to be inactivated chemically or metabolically prior to reaching their site of action. Also, as the dose reduces, the time to tumour appearance increases — hence when doses are very low, tumours only become apparent late in life and so make only a small contribution to reduced life expectancy. At very low doses it is possible to predict that the animal dies of other causes before the cancer develops, but of course this is an untestable hypothesis.

In summary, it is important that as much as possible is known about the mechanism of a cancer-causing agent, so that the appropriateness of the animal model can be assessed. The activity of the chemical in mutagenicity tests and transformation assays is also important.

APPENDIX C[3]

Public Perception of Risk from Chemicals

1. Introduction

Following a request from the Environmental Health Unit, Health Research Services conducted a study to describe public attitudes to the use of pesticides. Concern about this issue has been raised by some individuals and community groups within New Zealand and there appears to increasing public awareness that pesticides may cause acute chronic sickness in humans. At the same time, the regulations controlling the use of pesticides in New Zealand are currently being reviewed.

In order to address this issue of public concern, research was undertaken to determine what is known and to identify the key concerns regarding the use of pesticides. This research involved a review of existing literature, a focus group interview, and a survey of the general public.

2. Aims of the Study

The aims of the study were:

1. To determine the general public's perception and level of concern about the risks of exposure to and harm from pesticides.
2. To determine what, if any, steps would be favoured by the public for education about the use of pesticides.

3. Review of Literature

A review of information on the proper use and toxicity of pesticides and their effects on humans accidently exposed to them was conducted. There is little or no current data on the frequency of illness due to pesticide toxicity in New Zealand, due mainly to problems related to notification of cases and diagnosis management. Little is known about the actual proportion of the New Zealand public who are concerned about, or feel that their health has been affected by, toxic chemicals and sprays. Following this review a two-phased project was developed involving a focus group interview and a survey.

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3 Permission by the Department of Health to publish this paper is gratefully acknowledged.

4. Focus Group Interviews

Before the questionnaire was written, a focus group interview was held by members of the Department of Health, with the Toxic Action Group and a local resident. This covered a range of areas, some of which were incorporated into the survey questionnaire.

After considering definitions, a range of concerns about pesticides were discussed, including the dangers of some particular pesticides, lack of knowledge about their effects, the perception that agencies charged with controlling use of pesticides were 'turning a blind eye', and a widespread lack of knowledge of the dangerous properties of some pesticides. The Toxic Action Group felt that the real level of effect on people was not known due to misdiagnosis by general practitioners and specialists. The Toxic Action Group wanted the Department of Health to be more proactive by co-ordinating with other agencies with a responsibility in this area, as well as undertaking public education.

5. Survey Results

A sample of 800 respondents was randomly selected from all New Zealand residents aged 18 or more. Dwellings listed in all regional telephone directories were used. The survey was conducted by telephone during June 1990. A summary of results is presented below.

1. When asked to identify the important health issues facing them today, respondents offered alcohol and its effects, pollution of the environment, cancer, the spread of AIDS, smoking and its affects, and the breakdown of the hospital system. Chemical sprays were a concern raised by seven percent of respondents, while chemicals added to food or water were an important issue for four percent of respondents.

   When asked to nominate the most important health issue for them, chemical sprays were mentioned by only three percent of respondents, while only one percent of respondents mentioned chemicals added to food and water. In contrast, the health issue that concerned New Zealanders most was the breakdown of the present hospital system — 19 percent of respondents nominated this as the most important issue.

2. Respondents were asked about their level of concern about a list of specific health issues. Alcohol and the effects of alcohol stood out, with 72 percent of the sample stating they were very concerned about this issue. Sixty percent of respondents reported being very concerned about the spread of AIDS. Coming

into contact with poisonous substances, such as pest and plant sprays or chemicals added to food, was a further area of concern. Of those surveyed, 44 percent were either 'very' or 'somewhat' concerned about both of these risks.

3. Of those who nominated either of these as an area of concern, a total of 28 percent of those surveyed were very concerned about contact with poisonous sprays and chemicals added to food. Sixteen percent were very concerned about exposure to sprays, but not food chemicals; and a similar proportion were very concerned about food chemicals, but not sprays.

4. Risk from harm caused by contact with poisonous chemicals was of less concern to respondents than the risk of injury from a road accident, developing a life-threatening illness, or being mugged or assaulted. However, sixteen percent of adult New Zealanders saw poisonous chemical contact as a definite risk to them individually.

5. A total of 13 percent of the sample felt they were definitely at risk from poisonous chemicals, but not from food poisoning. Personal injury from both sources was perceived as a definite risk by three percent of the sample, while four percent saw food poisoning as a risk.

6. Nearly 3 in 10 (29 percent) respondents felt that the risk of suffering personal injury in a road accident was greater than other specific risk factors. Six percent of the sample saw contact with poisonous chemicals as being their greatest risk. Only one percent of the sample felt that they were most at risk from food poisoning.

7. Forty-five percent of adult New Zealanders believed they have been exposed to herbicides and/or insecticides during the previous six months. Nineteen percent believed they had been in contact with fungicides.

8. Concern over contact (regardless of whether this had taken place or not) was highest for herbicides at 48 percent, followed by insecticidal exposure (39 percent) and fungicidal exposure (21 percent).

9. The proportions of the total sample who reported that they were concerned by, and those who had contact with, pesticides and other forms of chemicals or pollutants is given below:

	% HAD CONTACT	% CONCERNED OVER HAVING CONTACT
Household Chemicals	87	21
Noticeable Exhaust Fumes	45	64
Industrial Chemicals	31	32
High Levels of Air Pollution	16	56
High Levels of Food Additives	13	44
Lead Paint	7	36

10. A total of six percent of the adult population believe some illness they have personally suffered was caused by contact with chemicals, sprays, additives, or pollution. Another fourteen percent attributed the illness of a family member to such contact.

11. When asked whether they agreed or disagreed with a number of statements about chemicals, respondents tended to have very polarised views. These are outlined below:

87%	agreed	"the long-term health risks of chemicals are worrying"
86%	agreed	"not enough care is taken when people use chemicals"
85%	agreed	"there is not enough known about the health risks of using chemicals"
75%	agreed	"too many chemicals are added to food."

In contrast, high proportions of the sample disagreed with the following statements:

79%	disagreed	"there is too much fuss made about the risk of chemicals"
78%	disagreed	"the public know enough about the health risks of chemicals"
62%	disagreed	"the controls on the use of chemicals are adequate"
56%	disagreed	"all pesticides, herbicides and fungicides should be banned."

12. Just under half of the sample (46 percent) were sure that chemical spraying had been carried out near their homes. Those responsible for spraying were reported

to be neighbours (37 percent), followed by local authorities (30 percent), farmers (23 percent), and orchardists/market gardeners (20 percent).

13. Nearly half (49 percent) of the sample appeared to be satisfied with current labelling information on chemicals. Somewhat fewer (37 percent) expressed similar satisfaction about labels of additives contained in food.

14. The main items of information respondents stated they wanted on chemical labels were a description of the possible harmful effects of the chemical on health (40 percent); detailed handling instructions covering storage, mixing, using and disposing of chemicals (36 percent); and a listing of ingredients (20 percent).

15. The main items of information wanted on food labels for food with additives were an additive listing (24 percent), full ingredient listing (22 percent), possible harmful effects on health from consumption (18 percent), and quantity of additives (13 percent).

Summary

The survey findings indicate a significant level of public concern over risk from pesticides. However, a number of issues such as a perceived decline in the hospital system, misuse of alcohol, and the spread of AIDS, were seen as more important. The use of pesticides was not an issue that arose unprompted.

While there was little support for an absolute ban on these products, there appears to be considerable support for more regulatory control. There was also support for increased public awareness and education to cover other so-called 'pollutants' perceived to cause damage to both health and the environment.

There is consistent concern about the use of pesticides and fungicides, although such chemicals are not seen as immediate threats. With the growth of 'green consciousness', which is fostered by groups such as the Toxic Chemicals Group, the Green political party, commercial companies and the media, it is possible that this concern will grow significantly in the future.

It could be useful to conduct a similar survey in 1995 to check if public attitudes have changed and any possible resultant interest in regulation and education.

RISK ASSESSMENT AND FIRE SAFETY INSPECTIONS

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The New Zealand Fire Service is actively involved in inspecting and reporting on premises in relation to fire safety, fire protection and fire prevention.

Our approach is not one of a quantified risk analysis as such, rather it is concerned with analysing premises and the contents and activities therein, and identifying risks and making appropriate recommendations to reduce the risk and impact of a fire occurring.

All of the premises we inspect are subject to Territorial Authority Bylaws and many are subject to specialised Codes of Practice which recognise the risks likely to be present in a given type of occupancy and specify the measures which must be taken to mitigate those risks.

These Bylaws and Codes of Practice have been developed by a committee and generally reflect a consensus view, although I would emphasise that not all members of the committee necessarily agree with the final document in its entirety.

Generally, these documents are based on fire experiences both in New Zealand and overseas. In fact, in some cases they are overseas Codes which have been adapted and modified to suit New Zealand conditions and terminology.

While one could argue that these documents have not been developed from a quantified risk analysis perspective, their various provisions have been included because fireground experience has shown that a potential risk occurs and that measures must be taken to eliminate, or at the least reduce, that risk.

ACTS

(As at 15/5/91)

Acts Interpretation Act 1924 (Reprinted 1979)

Amendments	1979 no. 71
	1979 no. 128
	1983 no. 22
	1986 no. 115
	1988 no. 113
Regulations	1983/228
	1990/152

Archives Act 1957 (Reprinted 1979)

Amendments	1988 no. 130

Area Health Boards Act 1983

Amendments	1986 no. 16
	1988 no. 21
	1988 no. 50
	1988 no. 100
	1989 no. 32
	1989 no. 42
	1990 no. 79

Children, Young Persons, and Their Families Act 1989

Amendments	1989 no. 70

Children's Health Camps Act 1972 (Reprinted 1989)

Civil Defence Act 1983

Amendments	1988 no. 54
	1989 no. 33

Clean Air Act 1972 (Reprinted 1989)

Construction Act 1959 (Reprinted 1988)

Amendments	1989 no. 83

Coroners Act 1988

Dangerous Goods Act 1974 (Reprinted 1989)

Amendments	1989 no. 84

Disabled Persons Community Welfare Act 1975 (Reprinted 1990)

Education Act 1964 (Reprinted 1976)

Amendments	1976 no. 42
	1977 no. 91
	1978 no. 79
	1981 no. 124
	1982 no. 19
	1982 no. 155
	1982 no. 170
	1983 no. 57
	1985 no. 124
	1987 no. 14
	1987 no. 177
	1989 no. 80
	1989 no. 156
	1990 no. 118
Regulations	1976/225
	1979/164

Education Act 1989

Amendments	1989 no. 156
	1990 no. 60
	1990 no. 118
	1990 no. 134

Explosives Act 1957 (Reprinted 1980)

Amendments	1983 no. 71
	1985 no. 2
	1989 no. 85
Regulation	1990/34

Factories and Commercial Premises Act 1981

Amendments	1983 no. 72
	1989 no. 86
Regulations	1981/277
	1982/73

Fire Service Act 1975 (Reprinted 1991)

Forest and Rural Fires Act 1977 (Reprinted 1991)

Gas Act 1982

Amendment	1987 no. 31

Harbours Act 1950 (Reprinted 1979)

Amendments	1980 no. 54
	1981 no. 72
	1983 no. 6
	1988 no. 63
	1988 no. 92

	1988 no. 102
	1988 no. 132
	1988 no. 188
	1989 no. 71
	1990 no. 119
Regulations	1980/168
	1983/141
	1986/180
	1986/194

Health Act 1956 (Reprinted 1987)

Amendments	1987 no. 194
	1988 no. 99

Hospitals Act 1957 (Reprinted 1987)

Amendments	1988 no. 22
	1988 no. 65
	1988 no. 101
	1989 no. 36
	1989 no. 42

Local Government Act 1974 (Reprinted 1990)

Official Information Act 1982 (Reprinted 1988)

Amendments	1989 no. 122
Regulations	1988/282
	1988/317
	1989/89
	1989/154
	1990/60
	1990/132
	1990/166

	1990/194

Sale of Liquor Act 1989

Amendments	1989 no. 134

Standards Act 1988

Town and Country Planning Act 1977 (Reprinted 1984)

Amendments	1987 no. 69
	1988 no. 44
	1988 no. 214

Toxic Substances Act 1979

Amendments	1983 no. 98
	1986 no. 111
	1988 no. 215
Regulations	1979/276

GENERAL ACTS

Accident Compensation Act 1982

Amendments	1983 no. 60
	1985 no. 66
	1985 no. 69
	1985 no. 166
	1988 no. 31
	1989 no. 52
	1989 no. 95
	1991 no. 16
Regulations	1984/343
	1987/182
	1988/124

Atomic Energy Act 1945 (Reprinted 1979)

Boilers, Lifts, and Cranes Act 1950 (Reprinted 1979)

Amendments	1980 no. 101
	1988 no. 177

Carriage of Goods Act 1979

Amendments	1980 no. 102
	1989 no. 100

Defence Act 1990

Evidence Act 1908 (Reprinted 1979)

Amendments	1980 no. 6
	1980 no. 27
	1982 no. 48

	1985 no. 54
	1985 no. 161
	1986 no. 74
	1986 no. 87
	1987 no. 138
	1988 no. 116
	1988 no. 222
	1989 no. 104
	1990 no. 46

Forests Act 1949 (Reprinted 1988)

Holidays Act 1981

Amendments	1983 no. 126
	1990 no. 112
	1991 no. 26
Regulation	1981/277

Incorporated Societies Act 1908 (Reprinted 1981)

Amendments	1981 no. 41
	1983 no. 54

Machinery Act 1950 (Reprinted 1986)

Amendment	1989 no. 88

Marine Pollution Act 1974 (Reprinted 1989)

Amendment	1990 no. 34

Mental Health Act 1969 (Reprinted 1988)

Regulation	1988/131

Noise Control Act 1982

Amendment	1988 no. 84

Pesticides Act 1979

Amendments	1987 no. 16
	1987 no. 44
Regulations	1981/177
	1983/15

Petroleum Act 1937 (Reprinted 1981)

Amendments	1981 no. 153
	1985 no. 35
	1988 no. 78
Regulation	1988/63

Police Act 1958 (Reprinted 1990)

Amendment	1991 no. 29

Radiation Protection Act 1965 (Reprinted 1986)

Tasman Pulp and Paper Company Enabling Act 1954

Amendment	1986 no. 29

Transport Act 1962 (Reprinted 1985)

Amendments	1985 no. 126
	1985 no. 194
	1986 no. 49
	1987 no. 96
	1988 no. 139
	1988 no. 170
	1989 no. 77
	1989 no. 158
	1990 no. 135

Regulations	1986/324
	1987/273
	1987/274
	1987/341
	1988/234
	1988/324
	1989/140

Trespass Act 1980

Amendments	1981 no. 99
	1987 no. 164

REGULATIONS RELATING TO FIRE SAFETY

(As at 15/5/91)

Asbestos Regulations 1983

Amendment	1	1986/300

Camping Ground Regulations 1985

Children and Young Persons (Residential Care) Regulations 1986

Amendment	1	1989/297

Construction Regulations 1961 (Reprinted with Amendments 1-10, 1981)

Amendment	13	1987/337

Dangerous Goods (Class 2 - Gases) Regulations 1980

Amendment	1	1981/300
	2	1982/229
	3	1985/88
	4	1986/15
	5	1987/326

Dangerous Goods (Class 3 - Flammable Liquids) Regulations 1985

Dangerous Goods (Class 4 - Flammable Solids or Substances and Class 5 - Oxidising Substances) Regulations 1985

Dangerous Goods (Labelling) Regulations 1978

Amendment	1	1985/44
	2	1987/302

Dangerous Goods (Licensing Fees) Regulations 1976

Amendment	1	1981/257
	2	1983/128
	3	1986/234

Dangerous Goods Order 1983

Dangerous Goods Order 1987

Dangerous Goods Regulations 1958

Amendment	4	1969/47
	5	1970/255

Electrical Supply Regulations 1984

Amendment	1	1986/243
	2	1987/91
	3	1988/264
	4	1991/62

Electrical Wiring Regulations 1976

Amendment	1	1979/184
	2	1987/90
	3	1987/178
	4	1987/391
	5	1988/273
	6	1989/180
	7	1990/274

Explosives (Fireworks) Order 1990

Explosives Regulations 1959

Amendment	1	1967/182
	2	1977/144

	3	1978/54
	4	1978/304
	6	1986/233

Factories and Commercial Premises (First Aid) Regulations 1985

Films Regulations 1984

Amendment	2	1988/184
	3	1989/151
	4	1990/213

Fire Extinguishers Regulations 1958

Amendment	2	1968/119

Gas Industry Regulations 1984

Amendment	2	1987/347

General Harbour (Ship, Cargo, and Dock Safety) Regulations 1968

Amendment	1	1972/190
	2	1976/226
	7	1982/95
	8	1986/154

Heavy Motor Vehicle Regulations 1974

Amendment	1	1974/309
	3	1985/145
	4	1987/206
	5	1988/325
	6	1989/179
	7	1989/309

Kindergarten Regulations 1959 (Reprinted with Amendments 1-6, 1973)

Noxious Substances Regulations 1954 (Reprinted 1967)

Amendment	1	1981/366

Old People's Homes Regulations 1987

Petroleum Pipelines Regulations 1984

Petroleum Regulations 1978

Amendment	2	1988/328
	3	1989/144

Private Hospitals Regulations 1964

Amendment	1	1985/333

Radiation Protection Regulations 1982

Amendment	1	1988/52

Sale of Liquor Regulations 1990

Shipping (Dangerous Goods) Rules 1979

Shipping Fire Appliance Regulations 1989

Spray Coating Regulations 1962

Amendment	1	1975/221
	2	1981/367
	3	1982/220

Town and Country Planning Regulations 1978

Amendment	1	1981/104
	2	1988/191

Toxic Substances Regulations 1983

Amendment	1	1986/363
	2	1988/51
	3	1988/253

Wine Makers Regulations 1990

GENERAL REGULATIONS

Clean Air (Licensing) Regulations 1973

Amendment	1	1983/45
	2	1987/17

Clean Air (Smoke) Regulations 1975

Coroners Regulations 1989

Defence Regulations 1990

Pesticides Regulations 1983

Amendment	2	1985/196
	3	1987/217
	4	1988/54
	5	1990/8

Traffic Regulations 1976

Amendment	1	1978/72
	4	1980/31
	5	1980/115
	6	1981/158
	7	1981/311
	8	1982/93
	9	1983/282
	10	1984/31
	11	1984/169
	12	1985/70
	13	1985/144
	14	1985/289

	15	1987/213
	16	1988/171
	17	1988/187
	18	1988/326
	20	1989/312
	21	1990/159
	22	1990/333

Transport (Vehicle Standards) Regulations 1990

Water Supplies Protection Regulations 1961

Amendment	1	1975/7
	2	1985/149

STANDARDS

NZMP9:1989	Fire properties of building materials and elements of structure.
BS476	Fire tests on building materials and structures.
BS750:1984	Specification for underground fire hydrants and surface box frames and covers.
150 834:1975	Fire-resistance tests. Elements of building construction.
NZS1511:1960	Method of test for flame-proof materials.
AS1530	Methods for fire tests on building materials, components and structures.
AS1657:1985	Fixed platforms, walkways, ladders and stairways. Design, construction and installation.
AS1735	Lifts, escalators and moving walks.
NZS1900, Chapter 1: 1985	Preliminary.
NZS1900, Chapter 5: 1988	Fire Resisting Construction and Means of Egress.
NZS2139:1967	Specification for heat actuated fire detectors.
NZS3604:1990	Code of Practice for light timber frame buildings not requiring specific design.
NZS4208:1973 Replaced by:	Department of Health Code of Practice for Fire Protection in Area Health Board and Licensed Hospitals and Health Care Buildings (Parts 1 and 2)
	Department of Health Emergency Evacuation and Staff Training in New Zealand Hospitals and Community Care Buildings (Part 3).
NZMP4213:1974	Inspection procedure for field-applied sprayed fire protection materials.
NZS4216:1983	Code of Practice for design of meatworks complexes for fire safety.
NZS4231:1095	Specification for self-luminous EXIT signs.

NZS4232:1988	Part 1:1988	Performance criteria for fire resisting closures.
	Pars 2:1988	Fire-resisting glazing systems.
NZS4403:1976		Code of Practice for the storage, handling and use of explosives.
NZS4501:1972		Code of Practice for the location marking of fire hydrants.
NZS4503:1974		Code of Practice for the distribution, installation and maintenance of hand-operated fire fighting equipment for use in buildings.
NZS4504:1981		Specification for fire hose reels.
NZS4505:1977		Specification for fire fighting waterway equipment.
NZS4506:1978		Specification for portable fire extinguishers of the water, foam and dry powder types.
NZS4507:1978		Specification for fire testing and rating of portable fire extinguishers.
NZS4508:1979		Specification for portable carbon dioxide fire extinguishers.
NZS4510:1978		Code of practice for riser mains for fire service use.
NZS4511:1979		Specification for bucket pump fire extinguishers.
NZS4512:1981		Automatic fire alarm systems in buildings.
NZS4514:1989		The installation of smoke alarms.
NZS4515:1990		Residential fire sprinkler systems.
NZS4521:1974		Specification for boxes for fire brigade connections.
NZS4541:1987		Automatic fire sprinkler systems.
NZS4561:1973		Specification for manual fire alarms for use in buildings.
NZS5807:1980	Parts 1,2 & 3 & Part C	Code of Practice for industrial identification by colour, wording or other coding.
NZS6104:1981		Specification for emergency electricity supply in buildings.
NZS6742:1971		Code of Practice for emergency lighting in buildings.
NZS7401:1985		Specification for solid fuel burning domestic appliances.
NZS7421:1990		Specification for installation of solid fuel burning domestic appliances.

NZS8709:	Part 1:1984 Part 2:1985	Fire tests for furniture.
NZS9201:Chapter 3: 1972		Licensing and control of apartment buildings and boarding houses.
NZS9231:1971		Model bylaw for fire prevention.
NZS9232:1972		Model bylaw for precautions against fire and panic in theatres, public halls and assembly halls.

APPENDIX 1

Discussion of Papers

1. John Gardenier: "Risk Concepts"

Gardenier noted the threefold aspect of risk: its source, effect and consequence, each with its own probability of occurrence. The difference between individual and societal (collective) risk was emphasised. Various risk measures have been proposed, including: lost-time frequency, loss-of-life expectancy, mortality rate and fatal accident rate (FAR). These measures can all be expressed as a probability of experiencing an adversity within a specified period of time. He noted that human life expectancy corresponded to an annual fatality risk of 1 in 100, the probability of death at age 45 of 1 in 1000, and the annual likelihood of contracting cancer of 1 in 10000. These levels of risk have, in some countries, provided a basis for setting risk targets.

2. Roger Keey: "Risk Quantification"

Obtaining appropriate data on event frequencies and conditional probabilities was a particular problem in risk quantification, although some generic data are in the public domain. These data, however, refer to past experience and practice, and technology and safety standards change with time. In setting risk targets, difficulties arise because of variations in life expectancy with age and in the level of background hazards.

3. Hayes Perkins: "Risk Assessment and the Planning Process"

In introducing his paper, Perkins noted that planning authorities have used various means of regulating risk levels, from the 100-year mean return interval for flood plain development to the use of separation distances for mitigating the off-site effects of industrial hazards. Risk assessment can be an aid in the planning process through the evaluation of hazards and their consequences, and the development of risk-reduction policies. Although there are no guidelines for what constitutes 'acceptable risk', the degree of involuntary imposition of a hazard is a factor in its tolerance. Tribunals have ruled that 'feelings' are a valid factor to be taken into account, although they tend to give more weight to technical evidence of risk. Such feelings are sometimes called 'irrational fears', but is there a 'right' view on risks to be tolerated, which public debate and education will bring about? Ultimately, views are values-related, and values will not necessarily change with further education.

The Resource Management Act 1991 is likely to increase the need for quantitative risk assessment (see the Fourth Schedule to the Act, 1(e), p.299). The new Act is less prescriptive and more permissive regarding development options than the earlier planning legislation. While proposed management of hazards should appear in planning proposals, there was some doubt as to whether explicit risk-reduction policies should be included. Proponents would be open to the criticism that, if such policies have been identified, then they should have been adopted in the first place unless costs were clearly prohibitive. Any proposal should include the best practical means of reducing risks to acceptable levels.

Tribunal decisions become embedded in case law and are not normally reviewed in the light of experience. Perkins wondered if there had been any follow-up on the adequacy of the separation distances required for LPG installations; (the workshop thought not).

4. David Parkin: "Regional Council Perspectives"

Parkin covered a number of issues relating to natural hazards, disaster insurance and flood plain management. With regard to flooding in New Zealand, mortality is not the most appropriate scale for evaluating risk. The prime concern relates to economic loss and the misery associated with widespread disruption and evacuation. There is a warning period (about six hours in the Waikato and three to four hours in the Coromandel). A risk scale could be related to lost time for commercial activity, to numbers affected, or to economic loss.

The data are dynamic: each data point changes the mean return interval. Essentially, decisions are made from experience with earlier failures, and a decision which was 'right' at the time may have to be modified in the light of experience. Increasingly, the concept used is that of the probable annual risk of a stated event appearing, rather than the mean return interval.

The data are uncertain. Safety factors are an empirical response to confidence bands in data; the wider the band, the greater the safety factor needed. Parkin recommended that the extent of confidence, as well as the probable magnitude, should be included when reporting risk estimates.

5. Janet Gough: "Environmental Risk Assessment"

Gough began by noting that risk could be subdivided into various kinds:

1. *Real risk* being concerned with future hazard outcomes.
2. *Statistical risk* being evaluated from past hazard outcomes.
3. *Predicted risk* being calculated outcomes from system models.
4. *Perceived risk* being outcomes intuitively discerned by individuals.

These risks are different. Risk assessments can be qualitative or quantitative: the former incorporating explicit use of value judgments; the latter often using diagrammatic techniques, such as event and fault trees, with implicit value judgments to synthesize hazard outcomes.

Quantitative risk analyses, by their nature, provide a scale of values for comparing risks, but there are difficulties with qualitative methods in defining a scale that is common to various kinds of hazards. The Environmental Protection Agency of the USA ranks environmental risks by placing them into groups based on severity and the chance of mitigating any hazard. One problem with this approach lies in the coarseness of the ranking, leading to difficulties in setting priorities within each group of risks.

In discussion it was noted that all risks cannot be reduced. Resources are not unlimited — risks have to be managed. Also, legislative constraints are, by themselves, useless if they cannot be sustained in practice.

6. Michael Farrier: "Risk Quantification in Insurance"

Insurance is evaluated on a present-day basis, being related more to interest rates than past experience, except for very large claims. Premiums are normally based on the maximum possible loss.

The risk can be viewed from two aspects:

1. *Maximum possible loss* being the loss should all protective systems fail.
2. *Normal loss expectancy* being the loss should the protective systems work.

Risks are evaluated both qualitatively and quantitatively, in some cases involving use of reliability records and HAZOP analyses. Reduced premiums are given for loss prevention measures as the maximum loss expectancy is reduced. When premium rates are high, significant account is taken of the loss expectancy; when premium rates are low, the trade-off is minimal.

There is an ethical dilemma for the owner-occupier seeking insurance with regard to presenting relevant information about the risks that are being managed. Zealous attention to safety audits and risk assessments may reveal unforeseen hazards. Should the owner-occupier be penalised for disclosing these 'additional' risks? In the management of sites of high hazard potential, formal quantitative risk assessments assist in gaining re-insurance, with premiums based on perceived economic loss.

Low premium rates are the result of the insurance industry being oversupplied with cash. Under these conditions, when it is easier than usual to buy insurance, does the accident rate increase because companies need not be so careful?

Goodman commented in discussion that often there is a sudden shift from being insurable to uninsurability as the result of a major loss. It would be more desirable to smooth out the incremental risk.

It was noted that the Government is withdrawing from commercial disaster insurance.

Environmental impairment insurance is possible if management systems are perceived to be effective.

7. David Elms: "Risk Assessment in Civil Engineering"

Risk in civil engineering has focused mainly on the probability of failure, rather than its consequence. Failure and accident data are generally sparse and unreliable, except perhaps for transportation, while failure models are often poor. Calculated bridge failure frequencies may be in the order of 1 per 10 million per year, based on design criteria, with actual experienced failure rates in the order of 1 per 10 thousand, due to constructional errors and/or gross overloading beyond design limits. Quantified risk is thus not viable for all situations, and a required design procedure is sometimes better than prescriptive standards. Comparative risk is more reliable and often more useful than absolute risk as a yardstick for management decisions.

Elms summarised the application of risk management and assessment techniques as follows:

Structural engineering

Risk assessment procedures are embodied in Codes, with seismic hazards being of major concern. Vulcanism is not normally considered. Fire precautions relate to provisions to control the spread of fire. Bridge design is concerned with the economic and social costs of structural failure, and rarely with collisions. There are no clear risk standards for major dams that pose significant life-threatening hazards. Process plant structures (towers, tanks and reactors) may be subject to quantitative risk assessment because of process-related hazards.

Hydraulic engineering

Flood plain management is primarily concerned with economic loss and risk balancing.

Transportation

Rail safety studies may use quantitative risk assessments if the data are available, in contrast to road safety work for which accident data are relatively numerous.

Public health and environmental engineering

The use of quantified limits, such as fN curves, is considered by Elms to be controversial as a means of setting environmental risk standards. Full quantitative risk assessments can be expensive, and a three-stage process is suggested:

(i) a qualitative scoping study;

(ii) a pilot quantitative study concentrating on a limited area;

(iii) a full quantitative risk assessment if need be, with the process reviewed at each stage.

It was noted that some rapid-ranking methods, such as the Tweeddale-Keey hazard score evaluation, are essentially a means of undertaking a scoping study. Gardenier commented that an fN curve is the result of a risk assessment, not a standard; with 'N' being an appropriate consequence measure, such as the area being flooded or the damage cost.

Major natural disasters cause damage to social infrastructure as well as property loss. The social impact may be more long-lasting than physical damage which can be repaired more rapidly.

Proposed changes to the Building Code will have safety implications as the proposed Code moves away from prescriptive regulations to performance-based requirements. There may be freedom to choose the level of risk. A performance-based Code also assumes that the 'performance' can be measured. The design assumptions regarding risk levels (particularly in regard to natural hazards such as landslips) may not be understood by new owners of a building on transfer of ownership, and subsequent building modifications may reduce the integrity of the original structure. (The possible adverse safety implications of modifications are well known in the process industries, being the prime cause of the 1974 Flixborough vapour-cloud explosion in England which destroyed a complete plant with major loss of life).

8. Jennifer Boshier: "Environmental Management"

The Office of the Parliamentary Commissioner for the Environment is concerned with management of the legislative system that regulates the disposal of wastes and sewerage, with soil and water management, and with coastal planning and subdivisions. The social infrastructure is considered an important aspect of environmental management.

Boshier would like to see local authorities place more emphasis on risk management in decision-making. The Resource Management Act 1991 is not very explicit about management systems. Current examples of risk management include: Maui B development, flood plain warning systems, and land management in the South Island high country.

The Act contains the core concept of 'sustainable management', but there is little guidance on the criteria to meet this end. Risk assessment and subsequent management will address some of these issues, such as the protection of outstanding features and minimisation of environmental degradation.

In discussion it was noted that risk assessment is a means of screening future activities which involve a measure of risk. Risk assessment sometimes goes under other names, such as in the case of work by the Plant Protection Service (Gough).

Environmental monitoring can assess long-term hazards, such as compliance monitoring in respect of discharge permits to waterways; or reviewing the effect of policy, such as landfill options. However, policy review is rarely done (as in evaluating the effect of separation distances for LPG installations). There are some systems in place for monitoring water quality, but more information is needed on low-water flows as well as flood levels. Long-term trends can be a problem. For example, although cadmium levels have been set for Rhine discharges, heavy metal concentrations are still rising in the North Sea. Monitoring thus needs to be long-term and specifically focused.

9. Doug Bent: "Civil Defence"

Civil Defence is concerned with public safety following a major disaster, with the aim of reinstating a community's infrastructure and social routine. A Civil Defence Emergency is an event beyond the scope of the normal resources of individual emergency services. Civil Defence threats include both natural and technological hazards. Hazard analysis is viewed as threat assessment in which the threat is defined as the product of the effect and the probability of its occurrence within a given time period. The threat is not normally expressed in numerate terms.

Civil Defence is concerned with the effect, rather than the nature, of the hazard. Emergency planning reviews likely responses in the light of available lifelines and emergency services. Civil Defence would also maintain or reinstate information services immediately after any emergency.

The professions have a responsibility with regard to education about the impact of natural events. It was noted that Earth Sciences are only cursorily treated in the New Zealand school curriculum.

10. Jim Waters: "A Toxicological Perspective"

Toxicity is not a hazard; a toxic material may not be very hazardous if it is contained.

Toxicology is a procedure, rather than a risk assessment. It is based on determining nil-effect levels, either by setting a daily intake based on no observable effect or by calculating the total intake from residues in all sources. Experimental nil-effect levels are estimated from animal tests with large safety factors to account for differences in susceptibility between species and between individuals. Problems of extrapolating data to low levels exist, including the following:

1. There can be no exposure without a response;
2. There may be a threshold response if natural release mechanisms are assumed;
3. Latency may be an inverse function of exposure.

Table 2 of the paper illustrates the variability of presumed 'safe limits' due to differences in assumptions in extrapolation. Authorities may even differ in the choice of models (see Table A1 on Standards for dioxin exposure). Some limits imply impacts which could not be monitored. For example, the World Health Organisation's multistage, linear extrapolation model for bladder cancer arising from the presence of chloroform in drinking water, would suggest that one case would be observed in New Zealand every two years, based on an individual daily intake of two litres of drinking water. A further uncertainty lies in the fact that toxicity data are based on individual exposure to chemicals, whereas exposure is normally to a wide range of potentially toxic materials at low concentration levels.

Industrial exposures are covered by the Occupational Safety and Health Service, and not the Department of Health.

11. David Dowrick: "Seismic Hazards"

The consequential hazards of seismotectonic activity include: ground shaking and fault displacement; soil failure (with clay) and liquefaction; subsidence and landslides; mudflows, water waves, watercourse changes and groundwater discharges; with secondary dangers such as dam failures and fires. In New Zealand, losses due to fires are likely to be one-tenth that for shaking. Inferred seismicity has been mapped, indicating gross regional variations (see Figure 1 of paper). There may be local site effects which are superimposed over the regionally averaged hazard. The effect of liquefaction in ground subject to such behaviour is difficult to estimate, as is the extent of liquefaction in any given case. Sometimes densification follows liquefaction, but the soil can still be susceptible to seismic action as water may return depending upon the watertable level.

12. Warwick Prebble: "Volcanic Hazards"

Unlike technological and seismotectonic hazards (which show brittle fracture with visual evidence of the source strength), volcanic hazards arise from forces of unknown magnitude, deep magma chambers of indeterminate size. One may distinguish between the hazards of volcanic activity (such as ashfalls and lava flows) and those of volcanic legacy relating to highly sensitive, collapsing soils — as witnessed in the Whaio canal failure. Generally, there is an inverse relationship between magnitude and occurrence.

Geotechnical hazard maps have been prepared, notably for the central North Island, indicating the extent of hazard zones from particular volcanic and seismotectonic activity. Such maps assume that what has been seen in the past will happen in the future.

A hazard assessment of volcanic risk has been prepared for the Taranaki Regional Council based on the four-point ranking schedule used by the Federal Emergency Management Agency in the USA. Monitoring is useful for predicting impending activity of andesitic volcanoes (like Mount St Helens and Mount Egmont), and the extent of the debris zone and mudflows can be estimated with reasonable accuracy.

Basaltic fields (as in Auckland) are less predictable, but the magnitude of individual events is smaller. Nevertheless, up to one-fifth of the metropolitan population could be affected (by the need to evacuate the stricken area) in any future eruption in Auckland. There is no public investment in monitoring, and there are problems in assessing the risk as volcanic activity tends to cluster in time.

Dowrick noted that a survey undertaken by DSIR for the Treasury has indicated that the economic impact of major vulcanism in the Taranaki, Okataina or Auckland fields could be comparable to a major earthquake in the Wellington region. The refugee problem would be greatest for an Auckland event.

13. Keith McLea: "Industrial and Natural Hazards"

Currently, there is some variation in how workplaces are treated in the legislation (industrial premises, wharves and amusement places are considered in separate Acts). Under legislation being prepared, these differences will disappear. Foreseeable risk, based on recognized or common hazards, will be a matter for self-regulation. 'Unforeseeable' risk, arising from low-frequency, high-consequence accidents or low-level exposures to toxic substances over a long period of time, will still be a matter for prescriptive regulation. Under these revised arrangements, it is expected that the Accident Compensation Corporation will introduce bonus/penalty rates for employer levies based on safety performance to provide incentive for self-regulation.

The new Health and Safety in Employment Bill (expected to become law in 1993) may provide umbrella legislation for major accident hazard regulations (to apply to sites such as large petrochemical facilities). The Occupational Safety and Health Service has started to compile information from field staff for a database of workplace safety levels. These will be judged on the basis of safety management systems in place, scale of the likely hazards and size of workforce.

14. Petrus Simons: "An Economic Perspective"

Economic variables are often indeterminate. 'Risk' differs from 'uncertainty':

Risk refers to known or understood processes and events which can be rationally expected.

Uncertainty refers to unknown or ill-understood events which are surprises — that is, are neither expected nor anticipated.

The real world is a mix of risk and uncertainty. Risks can be calculated, taken or averted. Management is concerned with reducing the sources of uncertainty to a tolerable level of risk. Use of chaos theory may help in discerning structure (rationality) in apparently patternless hazards.

"If a statement can be refuted on the basis of probability, then one is dealing with risk; otherwise, it is uncertainty."

15. Gary Goodman: "Local Government Viewpoint"

Natural hazards are often uncertain in the sense of having 'dynamic data'. Each event changes the database and the risk estimation.

Under present regulations, there are legal constraints on rehabilitation once a hazard has manifested itself (such as flooding). No building permit may be issued if it is known that the proposed building is likely to be damaged during its useful life. However, the new Building Bill will shift the responsibility for managing risks to the owner. There will be a need to formally document the hazards of a given site so that information can be transmitted to the owner Also, the proposed arrangements would require removal of the local authority's legal liability for negligence (perhaps to be replaced by a new liability on analysts who produce hazard maps!).

The larger the disaster, the greater the attendant misery. The effects of large-scale evacuation can be more traumatic on a community than individual fatalities. We do not cope well when a whole community is affected, compared with when only a few individuals or families are in need of support.

Local authorities are shifting responsibility for many engineering services to contractors, thus reducing the local authorities' ability to manage risk. Because a subtle shift of knowledge occurs on transferring activities, there is still need for a technical cadre to retain interpretive and evaluative capabilities.

Hazardous events or risks are not acceptable to a community if these events or risks persist. Goodman suggests that a danger is tolerated if it happens once in a lifetime (corresponding to a one percent annual probability of occurrence). This idea is echoed in Keey's frequency scale of remoteness based on the use of the 100-year return interval.

Hazards can be avoided, rather than protected against. Development on a flood plain can be restricted, rather than allowed behind a stopbank which may be breached or overtopped.

16. Eddie Graham: "Electricity Distribution"

Electrical supply services are undergoing change. As the new supply authorities become more profit-minded, risk could be increased if inspectorial services are curtailed.

Individual authorities keep their own records of non-supply, and these are not always compatible. It would be useful to have a national database of power interruptions.

17. Paddy Wright: "Fire Safety"

Problems are identified through the fire incident reporting system. For example, many failed chimneys in the Edgecumbe earthquake showed evidence of charring of timbers, presumably caused by overheating from solid-fuel heaters built into fireplaces.

Wright voiced concerns over the fire safety aspects of property protection which could arise under the provisions of the new Buildings Bill, when the individual would set the standard. The onus would then be on the owner to gain certification of fire resistance.

He also noted that the testing of electric blankets actually increased the incidence of blanket fires, due to interference with the wiring arrangements.

The data summary of incidents attended by the Fire Service is available as an Annual Report.

18. Bill Frith: "Road Safety"

In New Zealand, the fatal accident rate is three per billion vehicle km and the individual annual risk of death is 1 in 3000. By world standards for developed countries, the accident rate per capita and per vehicle is high, but low when expressed per vehicle-km, reflecting the lengthy average of trips undertaken. Accident data can be gleaned from reported incidents, hospital records and statistics produced by the Accident Compensation Corporation. The cost of a fatal accident is now assessed at $2.5 million, and that of a serious injury at $85 000.

Deregulation has increased the load limits able to be carried which, in turn, has mitigated the effect of the increase in tonnage on traffic hazards.

APPENDIX 2

Workshop Conclusions

1. Risk and Hazard

Despite a perceived commonality of concepts, doubt was expressed as to whether a common description of 'risk' could be devised, irrespective of the hazard being considered. A single set of definitions may have limitations. Nevertheless, the following definitions were seen to be widely applicable to risks and hazards of various kinds:

1. *Risk* is the probability of a specific hazard, loss or detrimental outcome happening within a defined period of time.
2. A *hazard* or *danger* is a threat which, should it happen, may pose an adverse effect on the environment.
3. The environment includes ecosystems and their constituent parts, including people and their communities, natural and physical resources and amenity values.

(Adapted from the Resource Management Act 1991)

2. Risk Ranking Methods

Various short-cut methods for ranking risks were noted:

1. Gough, in her paper, commented that environmental policy and natural resource managers in Washington State had developed a six-level ranking method for assessing environmental hazards.
2. Prebble mentioned that the Federal Emergency Management Agency of the USA had developed several formulae for ranking hazards, one of which has been used to rank perceived volcanic hazards in Taranaki. In the chosen method, four factors — history, vulnerability, maximum threat and probability — are graded on a 10-point scale.
3. Keey (*Trans IChemE*, Vol 69, Part B, 1991:85-89) has published an assessment method for industrial hazards based on a method developed by Tweeddale and Wood, which was used to evaluate hazards in the Rosebank Peninsula, Auckland. To produce a hazard score the method involves estimating the frequency, the consequence and the chance of mitigating or blocking an incident should it occur.

The Occupational Safety and Health Service of the Department of Labour has inaugurated a new information database of industrial accidents which, it is hoped, will provide a basis for ranking workplace risks (McLea).

It was proposed that these methods should be compared to determine whether one technique might be used to rank both industrial and natural hazards.

3. Comparison of Natural and Industrial Hazards

Public perception of the tolerability of hazards often depends on the actual or perceived degree of control exercised by the responsible person or authority, as shown in the following examples:

1. Industrial plant - the owner-occupier (high degree of control)
2. Flood plain - the local territorial authority (moderate degree of control)
3. Volcano - an 'act of God' (no degree of control).

Natural events are normally considered to be blame-free, although human activity (such as building on a flood plain) may enhance the consequence, whereas industrial and other accidents are normally assumed to be the results of culpable acts. Man-made and natural hazards, however, may be viewed in the same way if they are seen to be associated (such as fire).

While seismotectonic and volcanic hazards cannot be controlled at source, industrial and other risks of human activity can be constrained by regulations and statutes. Such hazards may be avoided, eliminated or mitigated. Risk tolerance can at times be low, with a small incremental risk from proposed industrial development giving rise to public opposition.

4. Applicability of Overseas Risk Criteria

In practice, overseas guidelines can provide useful risk targets as long as the risk standards are not formally adopted without adaptation to the New Zealand context, which is unlikely in the present deregulatory environment.

5. Additional Tolerable Risks Over Background

In areas of high natural (background) hazard, any additional risk may be regarded as unacceptable. Industrial hazards may compound an existing risk, for example, location of industries with high hazard potential in zones of major seismotectonic activity. Communities will react differently to perceived hazards, and their attitudes may be an appropriate topic for sociological research.

Decisions about prudent development presume the existence of hazard maps. The Scientific Advisory Committee of the National Civil Defence Organisation has groups examining the geography of various natural hazards. This information, when available in published form, might lead to changes in Building Codes. In the central North Island, for instance, volcanic hazards pose similar economic risks as those seismotectonic hazards which are taken into account in existing Codes.

Second-generation maps illustrating lifeline systems may be useful. Also, in some areas (such as Taranaki), an overlay of natural and industrial hazards might be important in developing protective strategies. Consequence modelling and the development of iso-risk contours may be a required feature of safety assessments under regulations being developed for the control of major industrial hazards (McLea).

6. Local Authority Response Under the Resource Management Act

The scope of local authorities' action under the new Resource Management Act 1991 is largely prescribed, although the extent of technical support and the need for formal risk assessment is uncertain.

7. Incorporation of Perceived Risk in Assessments

Planning Tribunals vary in the weight they give to public perception in hearings. Factors other than the calculated technical level of risk may be determinative, as in the hearing concerned with the proposed medical irradiation plant for Auckland.

In contrast, the Health Department adopts the World Health Organisation's technical guidelines when setting toxicological standards. The validity of these risk levels has not gone through any New Zealand political process. The activities of the proposed Hazards Control Commission, if set up under new legislation, would provide a more public process of review.

8. Database Management

Currently, failure incident and accident information is held in a number of databases:

1. The annual review of incidents attended by the New Zealand Fire Service.
2. The accident database set up by the Occupational Safety and Health Service.
3. Records of compensated accidents (accidents to persons away from work for more than one week) held by the Accident Compensation Corporation.
4. The earthquake damage database held by the Earthquake and War Damage Commission. (These files, which relate to insurance claims, are private and only available for restricted study in confidence.) This database will become less useful

when the Commission withdraws from covering industrial and commercial property.

5. Traffic accident data collected by the Ministry of Transport.

Access to failure information and reliability data is crucial for quantitative risk assessment. There are access restrictions whenever incidents are subject to insurance claims. Companies are also reluctant to divulge maintenance information for safety assessment research, lest such studies reveal unwelcome deficiencies with insurance implications.

A national failure database for accidents and industrial disasters would provide more complete coverage with a single point of contact, but universal data might not address specific end-user needs. At the moment, a national database guide might be sufficient for present purposes. However, if quantitative risk analyses become a recognised aspect of safety assessments under future legislation, then a central, more universal database would facilitate this.

When local data are incomplete or missing the only alternative is to use overseas data adjusted, as far as possible, for local conditions. Translation of data in this way is not always satisfactory.

9. National Facility for Quantitative Risk Assessment

Facilities exist overseas for quantitative risk evaluation, such as the Major Hazard Assessment Unit in the UK and the NSW Ministry of Planning's Major Hazard Policy Unit in Australia.

As far as natural hazards are concerned, the various New Zealand units seem to be functioning efficiently. However, should quantitative risk assessments be required under the Resource Management Act 1991, then some information resource on assessment methods might be useful, although the need for a risk analysis group could be met by commercial interests in New Zealand with links to overseas groups.

Nevertheless, a networking of those interested in risk evaluation would be valuable, and it was noted that Janet Gough of the Centre for Resource Management was prepared to co-ordinate the activities of an interest group for the time being.

APPENDIX 3

Review of the Warren Centre Report on "Major Industrial Hazards"

Roger B Keey

In 1986, the Warren Centre of the University of Sydney undertook a project on hazard identification and risk control for the chemical and related industries, with Dr David Slater, a founding director of Technica Ltd in the UK, as Visiting Fellow. A large number of project fellows and associates comprised the study team which was drawn mainly from industry and safety-related professions in New South Wales.

The project was set up in response to "pressures in Australia for more visible control of industry and industrial development." The Project Report noted that overseas industry has responded by adopting more stringent safety precautions, with quantitative risk assessment becoming an accepted tool in better engineering design and planning decisions. Essentially, the project was concerned with examining this technique and disseminating it to the wider industrial community in Australia.

The Task Group on legislation produced a set of policies that it suggested Australian regulatory authorities should adopt. These included:

1. Uniformity of standards to ensure a balance between involuntary risks imposed on society and semi-voluntary risks in the workplace.
2. Policies to ensure continual improvements in safety standards in a "reasonable, practical and cost-effective fashion", making a distinction between new and existing installations.
3. Legislative provisions that allow policies to be modified to suit changing community needs and technological developments.
4. Legislation that would be enabling rather than prescriptive, encouraging the greatest possible self-regulation, and supported by separate policies and guidelines.
5. Guidelines acknowledging that quantitative risk analysis as the most satisfactory way of demonstrating 'safety', indicating rather than prescribing risk criteria as acceptance standards.

In New Zealand many of these foregoing principles will be embodied in the proposed Health and Safety in Employment Bill which is expected to become law in 1993. However, it is uncertain to what extent statutory authorities in New Zealand will demand full quantitative risk estimates in safety studies and development proposals. Scoping studies and rapid-ranking methods may be all that is required or feasible in many cases, particularly when natural and environmental hazards are to be considered .

A second task group of the Warren Centre study was concerned with hazard identification and reliability data. It was considered that a structured review such as HAZOP (hazard and operability study) best enables past experience to judge the future operability of a facility. This technique is a widely accepted means of assessing the detailed design of a process plant when a piping and instrumentation diagram of the process has been completed, and is in use in New Zealand. The method could be extended to any activity that involves flows of items, such as in manufacturing assembly lines or highway networks.

A third task group reviewed consequence modelling for calculating the effects of major process-related hazards such as fires, explosions and releases of toxic substances. The reviews provide a useful compilation, but other publications such as the *World Bank Handbook* would be more helpful for anyone attempting a hazard analysis with limited experience. Perhaps the most important result of the Task Group's work was the production of two desktop computer programs to complement the consequence modelling. One disk contains a fault-tree drafting and calculational routine running on Lotus 1-2-3 spreadsheeting software. The other disk calculates individual and societal risk from input data on event frequencies and consequence distances, meteorological information and population densities. The program computes individual risk at grid points from which risk contours may be drawn; it also provides the fN data points from which the risk profile (fN curve) may be plotted.

Hazards associated with distributive networks were considered by a fourth group. The moving of hazardous materials introduces special problems, compared with those at fixed sites, because of the 'open' (less supervised) nature of most modes of transportation. The Task Group reviewed a number of case studies, and noted that quantitative risk analysis is useful both for screening transport options and in emergency planning.

Although the Warren Centre Project was an impressive undertaking, the scope of the study was essentially confined to major hazards arising in the processing and transport of dangerous materials. It therefore addresses only one aspect of the CAE Project which is concerned with the evaluation of both industrial and natural hazards of a major kind. Not all of the techniques useful in process analysis can be applied in a wider context because of differences in databases and in the nature of the threat. Therefore, the investigation of alternative hazard-ranking methods suitable for both industrial and natural dangers is one of the recommendations arising from the CAE Workshop.

To some extent, the conclusions of the Warren Centre Project have been overtaken by more recent events. Lessons learnt from the tragic destruction of an oil-production platform (Piper Alpha) in the North Sea in 1988 have drawn attention to the need for ongoing (life-cycle) safety management. Following the Cullen Report, safety requirements for offshore installations in the UK sector will almost certainly be changed, with implications for Maui B developments. A runaway reaction in a large chemical plant in northwest England in early 1990, which led to widespread destruction when the reactor exploded, has emphasised the need to re-assess old plant and processes in the light of new knowledge and techniques to determine whether they constitute any hazards.

Despite improved safety systems, evidence from insurance records suggests that problems may be getting worse or that losses are larger due to capital intensification. Redmond, Chairman of the Loss Prevention Panel of the Institution of Chemical Engineers (UK), comments in the *Loss Prevention Bulletin*, No. 100, August 1991:

> The severe effect of losing experienced staff and hence corporate memory results in poor application of safety standards in all areas of operation, leading to severe losses and incidents. I don't pretend to have an answer to this problem but I would appeal to responsible executives to keep the loss of experienced personnel down to a minimum during these periods of financial constraints and at the same time to maintain safety training programmes and safe design reviews.

Similar financial constraints and loss of experienced staff have taken place in New Zealand in recent years.

APPENDIX 4

Workshop Recommendations

It was agreed THAT:

1. A definition of 'risk' and 'hazard' be drawn up to cover dangers for both natural events and human activity.

   (Study group: Elms, Gough, Keey [convener])

2. An appraisal be undertaken of the applicability of rapid-ranking methods for evaluating natural and industrial hazards.

   (Study group: Boshier, Elms, Gough, Keey [convener])

3. The feasibility of drawing up overlaid risk and hazard maps for industrial and natural hazards be investigated, with the Taranaki region as a possible example, together with the possible significance of such information for presenting public risk and in setting building codes.

   (Study group: Dowrick, Prebble, Gardenier [convener])

4. The philosophy of resource use and hazards thereof be further developed.

   (Study group: Simons, Gardenier [convener])

5. A failure and accident database guide be prepared.

   (Study group: Gough [network co-ordinator], Keey [convener])

6. The proposed formation (Gough) of a network of persons involved in risk evaluation be encouraged as the basis of a possible information-transfer arrangement.

   (Liaison with CAE project: Keey)

7. An annual workshop of similar format to the present one would be useful to maintain interdisciplinary contact, and the Centre for Advanced Engineering be invited to sponsor one in August 1992 as a specific follow-up to the current project.

   (Action: Gardenier and Keey).

APPENDIX 5

LIST OF PARTICIPANTS

1. Mr D P Bent, Commissioner, Ministry of Civil Defence, Wellington.
2. Ms Jennifer Boshier, Office of the Parliamentary Commissioner for the Environment, Wellington.
3. Mr David J Dowrick, DSIR Physical Sciences, Lower Hutt.
4. Professor David G Elms, Department of Civil Engineering, University of Canterbury, Christchurch.
5. Mr Michael Farrier, Risk Protection Engineer, M & M Protection Consultants, Auckland.
6. Mr William J Frith, Land Transport Division, Ministry of Transport, Wellington
7. Mr John Gardenier, Gardenier Consulting, Wellington
8. Mr Garry R Goodman, City Engineer, Palmerston North City Council, Palmerston North.
9. Mrs Janet Gough, Centre for Resource Management, Lincoln University, Canterbury.
10. Mr Eddy W Graham, former Chief Engineer, Tauranga Power Board, Tauranga.
11. Professor Roger B Keey, Department of Chemical and Process Engineering, University of Canterbury
12. Dr Keith McLea, Occupational Safety and Health, Department of Labour, Wellington.
13. Dr David T Parkin, Manager, Engineering Rivers and Drainage, Waikato Regional Council, Hamilton East.
14. Mr Hayes Perkins, Murray North Ltd., Auckland.
15. Dr Warwick M Prebble, Department of Geology, University of Auckland, Auckland.
16. Mr Petrus Simons, Economist, Integrated Economic Services, Wellington.
17. Mr Jim Waters, Toxicologist, Environmental Health Policy Group, Department of Health, Wellington.
18. Mr Paddy Wright, Acting Director of Fire Safety, New Zealand Fire Service, Wellington.