Environmental risk assessment for New Zealand

Eric Pyle and Janet D. Gough

July 1991

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TE WHARE TAOKA MO KA KAIWHAKAHAERE
CENTRE FOR RESOURCE MANAGEMENT

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A guide for decision makers

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Foreword

There is increasing public concern in New Zealand about environmental issues. This concern has been fuelled by mounting evidence of a global environmental crisis, and the realisation that New Zealand does have its share of environmental problems. Economic development has not taken sufficient account of environmental risk, and the environment has been subject to considerable stress as a result. In some cases social, ecological and economic values have been ignored, and the environment's ability to meet the needs of future generations has been compromised. With the legal adoption of the principle of sustainable management through the Resource Management Bill, existing and future developments need to be assessed for the risks they pose to future generations' wellbeing which includes their environment.

In this guide, which is the product of an ongoing research programme at the Centre for Resource Management, approaches to environmental risk assessment are outlined. Consideration is given to both the general character of the assessment process and the nature of specific techniques used within the process.

Environmental risk assessment can be used to provide information to resource managers on all decisions affecting the environment, including issues such as pesticide/herbicide use, sewage disposal, siting of hazardous plant and storage facilities, land classification and land-use controls, pollution discharges and economic strategies. The techniques involving environmental issues outlined in this guide will help decision makers to increase the likelihood that outcomes from decisions involving environmental issues will be sustainable.

Acknowledgements

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Figures

1 Introduction

In the context of this guide, environmental risk refers to all risk to the environment resulting from human development. The term 'environment' covers many aspects including: 'modified' environments such as cities and farmland; natural environments, for example forests, lakes and wilderness areas; and people, who are an integral part of the 'environment'. Therefore, environmental risk can encompass a wide range of issues, including health risk, for example the effects of pesticide use; financial risk, such as the cost of pollution clean-ups; and risk to the social fabric, for example the dislocation of society due to human-induced disasters.

The purpose of environmental risk assessment is to provide information about the possible environmental effects of a decision. This information can then be assimilated into decision-making processes or used to give advice to specific groups, such as land managers in erosion-prone areas, or visitors to sensitive ecological areas. Often, risk assessment information is used to evaluate different management options.

1.1 Purpose

This guide has two major functions. Firstly it provides a brief summary of the concepts used in discussing **risk**. Secondly, it outlines the characteristics of the risk assessment **process** and the specific **approaches** and **techniques** used within the process. A minimum number of references are given and the reader is referred to a selection of key items for further background reading. Where possible, New Zealand examples of the use of risk assessment procedures are cited.

Some suggestions for selecting risk assessment approaches and techniques are made in this guide. However, because risk assessment procedures vary from situation to situation (e.g. depending on the nature of risk, site of the risk), this guide avoids stating which techniques and approaches **should** be used. Rather, the selection of a technique and approach will call on the expertise of the risk analyst.

1.2 Context and application

New Zealand currently enjoys a 'clean-green' image. However, this impression is relative and results from a comparison of New Zealand's environmental problems with those being experienced by the rest of the world. In fact New Zealand does have significant environmental problems that require attention such as soil erosion, groundwater contamination, and the siting of landfills.

The task of incorporating the concept of environmental risk into the decision-making process has been receiving a great deal of attention overseas in recent years due to the increasing number of environmental problems being experienced and the larger and larger sums of money being sunk into solving them[1]. A major reason why these environmental problems occurred is because decision-making processes did not adequately assess risk to the environment.

The warnings from overseas experiences are clear. Without incorporating the concept of environmental risk into decision-making processes the size and number of environmental problems in New Zealand will continue to increase because environmentally damaging outcomes from decisions will not be adequately catered for. This is a crucial point for a country that relies on its environmental resource base (e.g. agriculture) for its social and economic sustainability.

The public sector has primary responsibility for environmental management. There are many tools that public sector agencies can use to plan the uses to be made of the environment, such as land classification, water classification, water right approvals, catchment management plans, economic strategies. Environmental risk assessment can be used to provide information for virtually all planning tools.

1.3 Structure

This guide is divided into two sections. Section A provides an overview of the risk assessment process. In Section B some of the common techniques and approaches used to assess risk are described. Some risk assessments in New Zealand are discussed and at the end of Section B the key points are summarised. The guide concludes with a list of suggested reading and a glossary.

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1 For example, the USEPA's toxic waste dump 'superfund' clean-ups.

Section A Overview of the risk assessment process

The aim of this section is to describe the process of environmental risk assessment. This section begins by considering the participants involved in the process of assessing environmental risk. It continues with the definition of some key concepts and concludes with the description of the risk assessment process.

2 The participants in the risk assessment process

Throughout this guide mention is made of the 'participants' or 'players' in the risk assessment process. These are now identified.

The aim of environmental risk assessment is to provide information to the decision-making process. Decisions are made by various types of agencies (both public and private) at different levels, either national, regional or local. This guide is concerned primarily with decision making at the regional government level.

There are three main groups of participants who may be involved in environmental risk issues at the 'regional' level of decision making.

- **Groups within the community** who are either directly or indirectly affected, including business, recreational and user groups and government sector representatives from district, regional or central levels such as the Department of Conservation, the Parliamentary Commissioner for the Environment.

- **Analysts** or **'experts'**, who attempt to assess risk objectively on the basis of various assumptions. Often analysts have scientific, engineering or mathematical backgrounds.

- The **decision maker**[2], who has the responsibility for making a decision.

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2 May be an individual, a group of people or an agency.

3 Risk and uncertainty in the decision-making process

3.1 Introduction: the nature of risk

Risk cannot be defined with absolute accuracy because we cannot measure risk until after events have happened. While we can estimate risk now we cannot measure it now because of the uncertainty associated with both the probabilities of an occurrence and the outcomes. These uncertainties force the decision maker to deal with many aspects of risk assessment using **subjective** rather than objective methods[3].

The decision-making process usually takes information from three main sources: technical, social and managerial. The information provided from these broad areas may vary due to uncertainties in assessing risk and different perceptions of risk. It is likely to be the decision maker's responsibility to decide which perspective is given precedence.

Most situations involving risk require the decision maker to make value judgements about the **particular** situation. Situations involving risk are often unique in terms of their physical, social and technical factors and there are often site-specific uncertainties. However, there are some **general principles** for environmental risk assessment that can be followed.

This section begins by considering the characteristics of risk and the related subject area of uncertainty, then examines the broad categories of risk that a decision maker may want to include in a risk assessment process. The information presented in this section is mainly found in Gough (1988) and Gough (1990).

3.2 Characteristics of risk

Any decision that has the potential to have some environmental impact will have an associated environmental risk.

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[3] Outcomes cannot be predicted in the face of uncertainty, thus value judgements need to be made about outcomes in uncertain situations. When uncertainty is present there can be no 'objectivity'.

Risk (encompassing environmental risk) has three basic elements (Figure 1):

- a choice of action (can be to remain with the *status quo*) which leads to,
- events that have a probability of occurrence,
- these events are associated with outcomes, which are often expressed in terms like 'magnitude', 'consequence', 'severity' or 'significance'. Negative outcomes are often called 'hazards'.

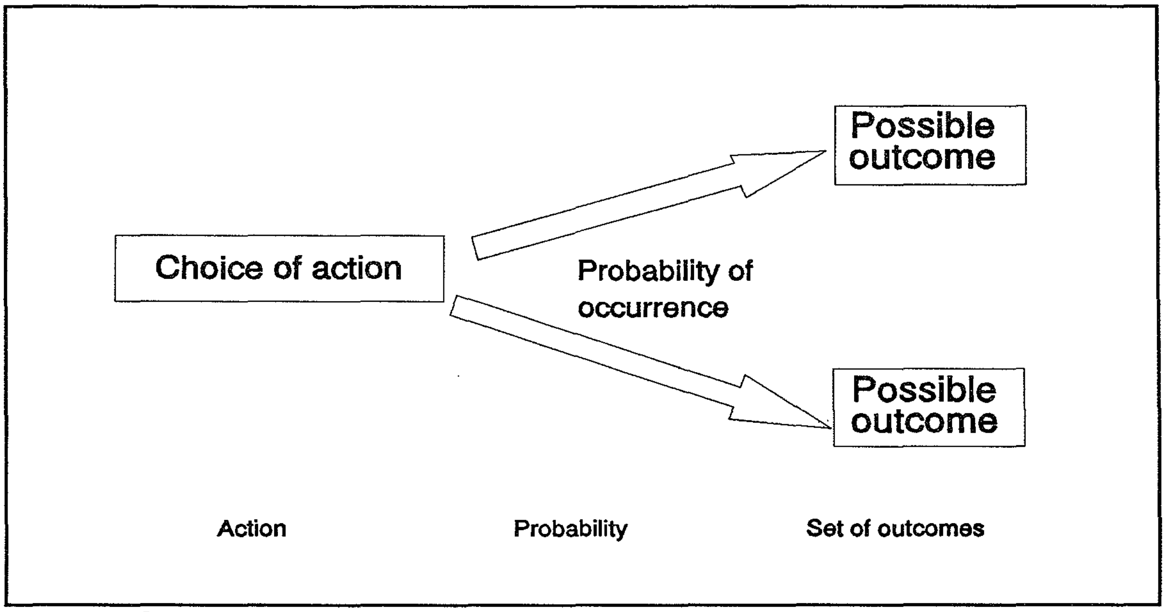


Figure 1 Characteristics of risk.

Risk concerns the **probability** of an outcome and the **magnitude** of the outcome. Similar outcomes with similar probabilities may have different **magnitudes** depending on environmental factors. For example, if the possible outcome is an oil spill the magnitude of this outcome will be larger near a marine reserve than on the open sea. Determining risk can be very **subjective** and is associated with uncertainty.

3.3 Characteristics of uncertainty

Uncertainty in the probability and magnitude of an outcome occurs when (Figure 2):

- there is a problem in 'defining the issues'[4],
- the probability of an outcome occurring is unknown,
- the set of outcomes is unknown, or
- magnitudes associated with outcomes are unknown (e.g. how 'significant' is an outcome?).

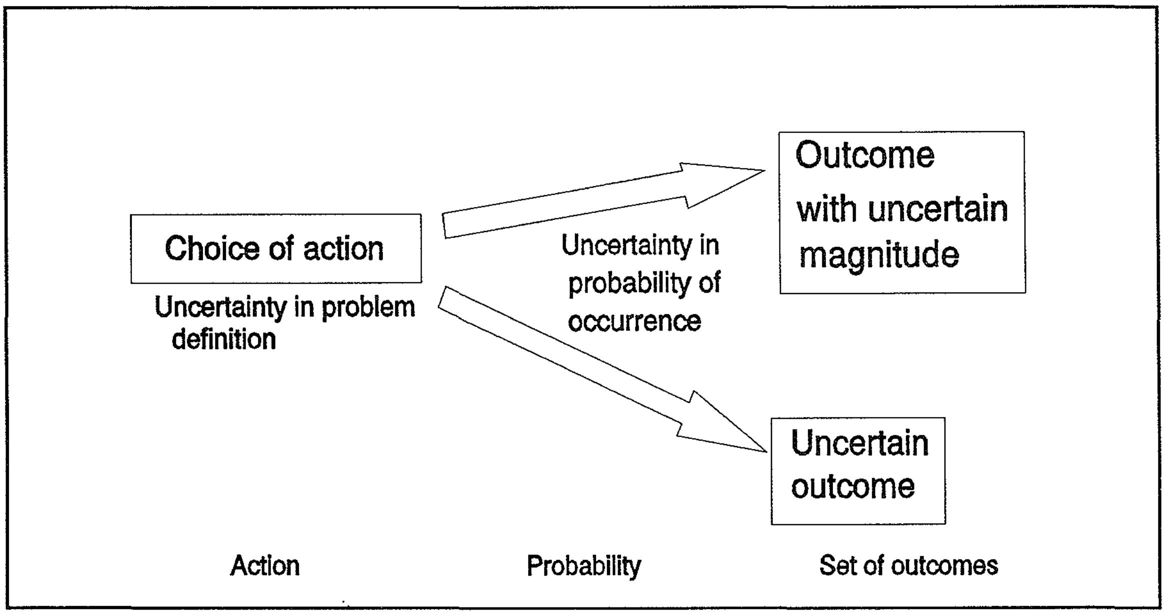


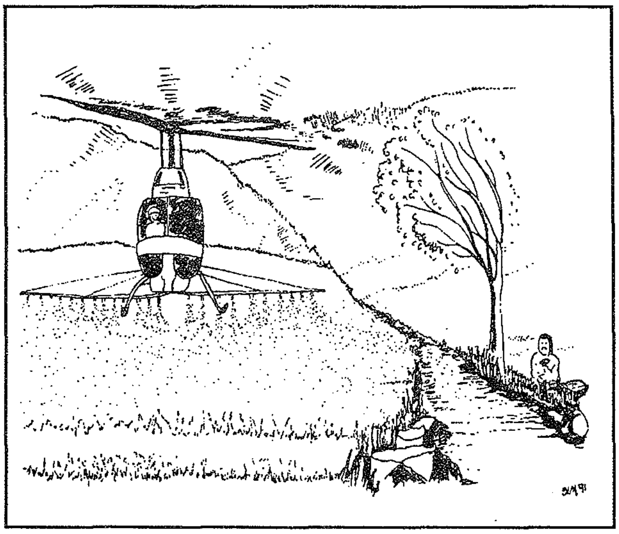
Figure 2 Characteristics of uncertainty.

Reducing uncertainty is in most instances desirable. However, before uncertainty can be reduced, it must be identified. Two approaches to reducing uncertainty are outlined.

The first way of identifying the presence of uncertainty involves seeking advice from many groups, including those at the community and expert level. Uncertainty exists if there is substantial disagreement as to what the 'problem' is, the levels of probability associated with outcomes, the likely set of outcomes, the magnitude of outcomes.

4 This concept is based on a branch of public policy theory that considers that the definition of the problem determines the outcome. Therefore, uncertainty in outcomes can depend on problem definition.

The corollary to this definition is that the identification of uncertainty will depend on the nature of the groups involved in the risk assessment process and the different perceptions they have.



"...PAC assumed certain conditions ... and these could not be met when 2,4,5-T was used in the 'field' ".

The second approach to identifying the presence of uncertainty applies to situations where the decision maker only uses expert assessments of risk. An expert's analysis of risk is based on certain assumptions. Uncertainty can be identified by considering the relevance of the assumptions to the situation at hand, for example, the British Pesticides and Advisory Board (PAC) considered that 2,4,5-T was 'safe'. However, PAC assumed certain conditions that applied to the 'ideal world' of the laboratory and these could not be met when 2,4,5-T was used in the 'field'. Analysis of PAC's assumptions shows that their risk assessment of 2,4,5-T application contained large uncertainties. Thus, decision makers **must** be aware of the **assumptions** made by experts.

3.4 Differentiating between risk and uncertainty

At the theoretical level the distinction between risk and uncertainty can be clearly made. However, in reality, risk and uncertainty become intertwined and the distinction between them becomes arbitrary. For example, at what point is there significant disagreement between participants in the assessment process? When are the assumptions used by experts applicable to a particular situation? In most instances it is not be possible to answer these questions absolutely and **every decision involves some degree of uncertainty.** Therefore, all decisions affecting the environment will involve aspects of both risk and uncertainty.

3.5 Types of risk

This section describes types of risk according to the way in which they are estimated.

Risk can generally be broken into four categories.

- Real risk: determined eventually by future circumstances when they develop fully.
- Statistical risk: determined by currently available data, typically measured actuarily.
- Predicted risk: predicted analytically from systems models structured from historical data.
- Perceived risk: seen intuitively by individuals.

Real risk is a hypothetical concept. Often it cannot be evaluated, because it can only be determined at some future time, when an event has either happened or it has not.

Statistical risk and **predicted risk** are very closely related. They are often called objective or technical estimates of risk. These measures of risk are generally calculated using frequencies or probabilities of death, injury or damage that are derived from recorded events and calculated populations ('real life' happenings). Simulation models can likewise be constructed to produce estimates of risk for situations that cannot be measured in nature. Examples of this type of calculation include models of nuclear power station explosions and leaks from chemical plants. These types of risk are normally expressed in numerical terms, for example an event may happen 'once in every 20 years'.

The difference between statistical and predicted risk can be quite subtle. Statistical risk tends to be based purely on historical happenings, whereas predicted risk incorporates the past information into systems models. The reliability of statistical risk estimates depends on similar conditions occurring in the future as have occurred in the past. The accuracy of predicted risk relies on modelling precision.

These types of technical measures can be challenged as being irrelevant in one-off situations. For example, the chance of dam failure can be 'objectively' calculated by using the number of dams and the number of failures. For a particular dam, however, these results may have little relevance.

Perceived risk is a judgement or valuation of consequences by individuals or groups of people. It is the most 'subjective' measure of risk and is used in many 'qualitative' risk assessment approaches. Perceived risk is normally expressed in qualitative terms such as 'large' or 'small'.

The distinction is often made between **subjective** and **objective** assessments of risk. Yet in reality, **all assessments of risk involve some subjectivity** because they cannot avoid containing elements of opinion. For example, technical assessment techniques rely on opinion to design experiments, select models, decide what weightings to assign to social importance, establish the way in which data are selected or derived, and even to decide upon the risks that are chosen to be studied. The concept of an objective risk estimate is therefore a misnomer.

The term 'actual risk' is often used in risk assessment and is also a misnomer. 'Actual risk' is usually used to describe scientifically calculated or experienced mortality and as such it is equivalent to statistical risk. However, 'technical risk' should not be termed actual risk, because technical estimates often contain considerable subjective bias as a result of data inadequacies, data selection methods, and the subjective selection of assumptions. This guide avoids the use of the term 'actual' risk because it is misleading.

4 The risk assessment process

The aim of risk assessment is to provide information to allow decision makers to make informed choices about management options. In the past, environmental risk assessment has mainly involved technical experts. However, this tendency is changing and overseas experience shows that risk assessment now involves extensive consultation with the wider community. While **techniques** for assessing environmental risk have changed, the basic **process** remains the same.

This section provides a brief outline of the risk assessment process. Specific risk assessment techniques are described in Section B.

4.1 Elements of risk assessment

There are three main parts to the risk assessment process (Figure 3). These interact to some extent and tend to overlap. They are:

- identifying actions and outcomes,
- estimating probabilities and magnitudes,
- evaluating the risks.

These three areas are now described.

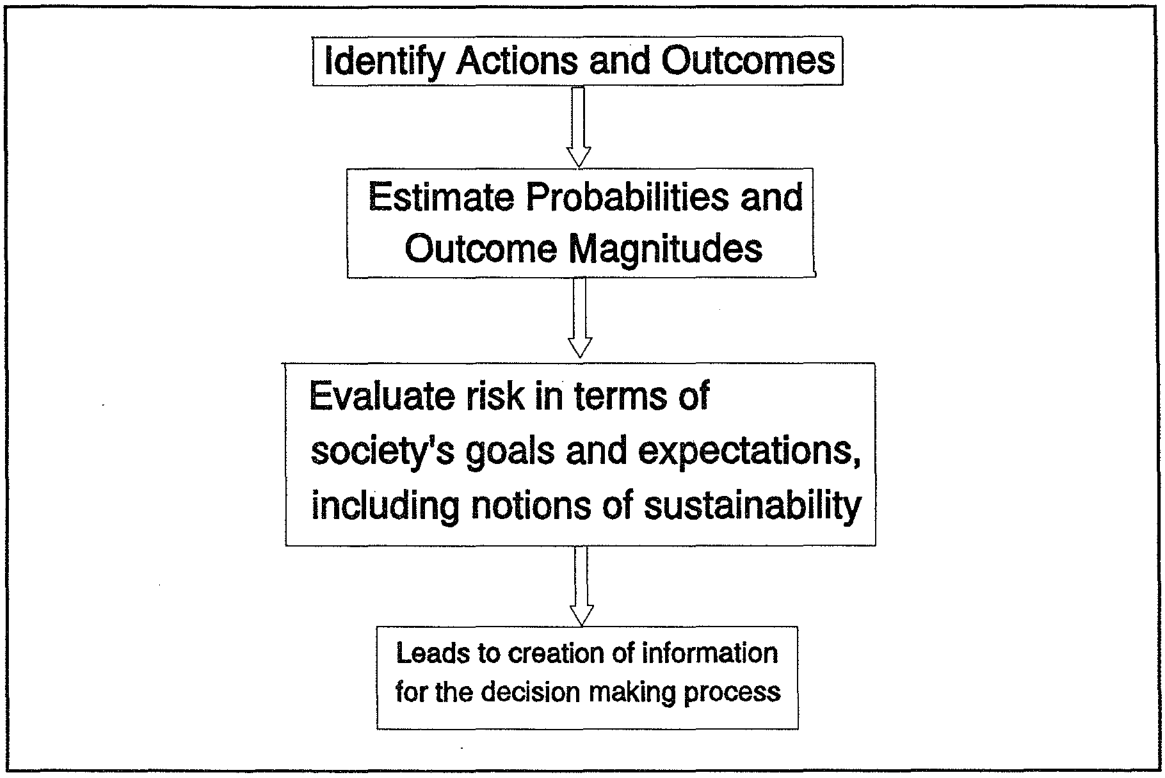


Figure 3 Framework for the environmental risk assessment process.

4.2 Identifying risks

The first step in the risk assessment process is to identify the risks. Risk identification involves considering the causes or origins of the risk (actions), whom or what is at risk (outcomes), as well as the conditions under which the hazard occurs.

Identified outcomes should not be excluded at this stage on the basis that they are 'insignificant'[5]. While some sections of the community perceive a risk to be 'insignificant', others may perceive the risk to be 'significant'. The decision maker must remember that all estimates of risk have subjective elements and therefore no risk estimates can be given automatic priority over another.

5 Insignificant may be decided by the decision maker or other participants.

There is no single 'right' technique for identifying risk. Techniques are likely to vary depending on the situation. A number of different methods may be used, including:

- traditional or folk medicine,
- commonsense assessment,
- analogy to well known cases,
- experiments on human subjects,
- review of inadvertent and occupational exposure,
- epidemiological studies,
- experiments on non-human organisms,
- test of product, or component performance.

4.3 Risk estimation

Once the actions and outcomes have been identified, their relative magnitude and probability must be estimated (either quantitatively or qualitatively). This will enable their relative importance to be evaluated. Risk estimation involves two aspects, estimating the **probability** and **magnitude** of outcomes. Thus, a risk estimate is the combination of the probability and magnitude estimates.

Estimating the probability of an outcome can be achieved by various methods. These methods are likely to produce different estimates, depending on the assumptions that are used. For example, one expert may consider that a pesticide will not cause harm to humans as long as it is below a certain concentration, while another expert may consider any level of pesticide has a probability of causing harm. Assumptions must be clearly defined so that the different participants in the process can appreciate how they each arrived at different measures of the probability of an outcome occurring.

Estimating magnitude of an outcome is often difficult. Often the public and 'experts' have different views on the relative importance of a hazard. There are no easy methods for aligning different estimates of outcomes and it may be better to consider all outcomes as having some importance and use the risk evaluation process to determine magnitudes.

In many instances technical estimates of risk are used. These are often expressed in terms that require extensive interpretation for the lay public (see for example any technical risk assessment report). This guide suggests that **decision makers** ensure that all risk estimates are presented in a form that can be comprehended by all participants in the risk assessment process.

4.4 Risk evaluation

The risk evaluation process is used to relate risk estimates to society's expectations and values. For example, a risk estimate may be small, possibly 'insignificant' in numerical terms, but for cultural reasons society may find the risk does not meet its expectations and is unacceptable.

Evaluating risk is a subjective process. Value judgements are required because:

- risk estimates themselves contain subjective elements and may vary depending on the method used to generate them,
- values placed on the estimates will vary depending on the views of the different participants,
- the physical setting will have a major influence on the value of the risk,
- the evaluation process includes analysis of the reliability of risk estimates and their applicability to the current situation - also issues that involve subjective assessments.

It is impossible to 'objectively' choose a particular 'right' value. Decision makers can make **defensible** choices if they use clearly identified sets of principles or criteria to guide the evaluation process.

4.4.1 Acceptable risk

The evaluation phase of the risk assessment process involves evaluating the level of risk that society finds acceptable. This discussion begins by considering what 'acceptable' means, and then past, current and emerging methods for establishing an acceptable level of risk are discussed.

Determining an acceptable environmental risk is concerned with safety and includes safety of ecological and social values. Something is 'safe' if its risks are judged to be acceptable. Setting an acceptable level of risk is a subjective exercise because safety concerns values.

The acceptability of risk raises three questions:

- acceptable in whose view?
- under what terms is a risk acceptable?
- for whom is the risk acceptable?

Originally, **technical experts' views** were used to set an acceptable level of risk. Experts defined an acceptable risk by comparing quantitative risk estimates to known and accepted risks, such as traffic accidents. This approach used three assumptions, all of which are now considered faulty. These are:

- that quantitative risk estimates are perfectly accurate, whereas often they contain large uncertainties,
- that society accepts one level of risk for all activities, whereas society prefers to accept **different** levels of risks for different activities,
- that death is the only value that is important, when in fact society considers that that is many values are important.

Thus, the technical approach, which relates environmental risk to the risks that society accepts in other activities, may not be an appropriate method for establishing an 'acceptable' environmental risk.

The limitations of the purely technical approach have led to the adoption of broader approaches. These approaches recognise that the level of acceptable risk is likely to vary depending on site-specific values that can be impossible to define accurately in absolute, quantitative terms. Currently, the setting of an acceptable risk is seen as a **process** that involves members of the community and agencies affected by a decision, both indirectly and directly. This approach encourages participation from a wide range of groups, including the affected community.

Very recently, an analogous concept to acceptable risk has been developed. 'Tolerable risk' depends on the idea of benefits outweighing risks. A tolerable risk is often associated with a specific time period or activity. In many cases people are prepared to accept a higher level of risk over a short time than they would accept over a longer period, that is, they will **tolerate** a risk under certain conditions.

Another emerging approach to setting an acceptable level of risk uses a 'precautionary principle'.[6] This approach is being adopted as a management tool in the Great Lakes region of North America and in some European countries as a consequence of the major environmental problems in these regions.

The precautionary approach involves the simple precept that: decision makers should err on the side of caution. The use of this approach means that a development project is assumed to have an unacceptable level of environmental risk (i.e. is unsafe) until it can be proved beyond doubt that the project has an acceptable level of environmental risk (i.e. is safe).

4.5 The role of the media in risk assessment

The current process for making risk assessments encourages community participation. Yet, to participate effectively, the community needs to be informed about the risks and uncertainties to which it is being exposed. In many instances the media will be the community's primary source of this information. This is a cause for concern to some participants because they feel that the media can be manipulated by interest groups and that it has the ability to influence the community's assessment of a risk. However, media researchers disagree and believe that the community is quite discerning in its assimilation of media reports.

A further concern is that the media may have difficulty communicating technical information, which is often complicated and loaded with jargon. Media involvement in risk issues does require experts to present their findings in a way that both the community and the media can understand.

4.6 The role of the technical expert

Technical experts are often asked to provide 'facts'. These 'facts' can have a crucial influence on the assessment process and experts can play a significant role in the risk assessment process.

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6 This technique is outlined further in Section B.

At times experts have experienced difficulties in providing relevant information that the other participants in the risk assessment process find credible. In many instances this situation has arisen because of differences between the environment in which the expert works and the risk assessment process (Rip, 1985).

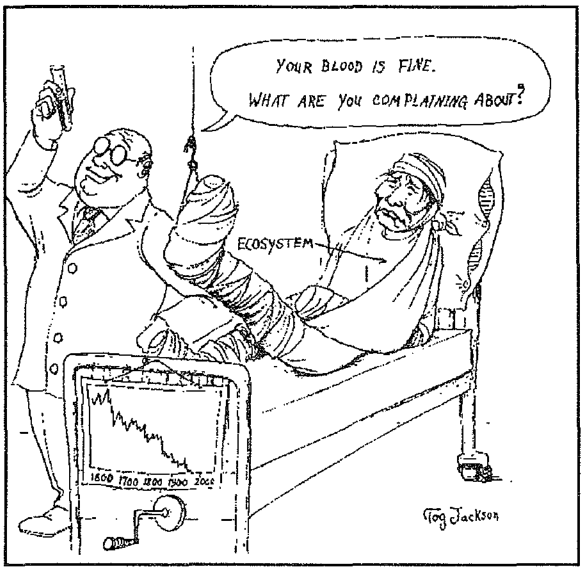
The expert's environment is very structured and has a clearly defined 'set of rules' that guide conduct and methods for presenting information. 'Facts' result from this structured environment with uncertainties being eliminated through the use of controlled experiments. In comparison, the risk assessment process, which often becomes political, may not be very structured in that various groups are involved and clearly defined rules are not agreed upon. 'Facts' may not exist due to the uncertainty associated with natural systems, and the different values that are held by the various groups towards the environment.

To provide relevant and credible information experts must become aware of the nature of public processes. Furthermore, they must openly acknowledge that the information they can contribute has limitations and is subject to uncertainty.

Section B Description of risk assessment techniques and approaches

5 Quantitative and qualitative risk assessment

Approaches to risk assessment can be divided into two broad categories: quantitative and qualitative. Quantitative techniques are used in an attempt to define risks objectively. Qualitative techniques are used as part of a more subjective approach in which value judgements are acknowledged as an integral part of the risk assessment process. In reality, **both techniques contain subjective elements**, because quantitative risk estimates are based on the subjective selection of certain assumptions.



"... *quantitative risk estimates are based on the subjective selection of certain assumptions.*" (cartoon adapted from International Joint Commission, 1978).

In this guide, quantitative techniques are recognised as providing subjective information and are defined as techniques that have a heavy reliance on numerical analysis. Qualitative approaches include all other techniques.

The aim of this section is to provide a description of commonly used quantitative and qualitative risk assessment approaches and techniques.

6 Quantitative (technical) risk assessment

The technical approach to risk assessment usually involves scientists and engineers, often from many different disciplines. For example, a technical assessment of the risk associated with a chemical plant would involve engineering analysis of the chance of a hazard occurring and also biological analysis to determine the potential harmful effects.

Uncertainties abound in technical risk assessments. These can be categorised as:

- completeness uncertainties - due to the analyst's inability to conceive of all possible scenarios, such as the errors made by the personnel operating a plant,
- modelling uncertainties - due to wrong assumptions or wrong equations being used to model scenarios,
- data uncertainties - due to uncertainties and errors in data used in the models.

Thus, technical assessments may not provide accurate risk estimates.

Quantitative assessments have been divided into clearly defined techniques (Vesely, 1984). These are:

- statistical analysis of past events having similar consequences,
- extrapolation techniques of past occurrences of less severe events,
- event tree analysis,
- fault tree analysis.

6.1 Statistical analysis of past events

Statistical analysis of past events is used when an event has occurred before and has resulted in a hazard at least as large as the one of current concern. The technique involves estimating the frequency[7] of a risk-causing event, by taking the number of outcomes in some 'exposure' time period. The exposure time takes into account the number of units or individuals that were exposed to the possible outcome during the time

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[7] Quantitative techniques provide either a frequency or probability estimate. Technical experts distinguish between these two, but both can be used to provide an estimate of the 'chance' of an event.

period. For example, the frequency of death from a particular hazard could be calculated by dividing the number of deaths by the total amount of time that people were exposed to the potential hazard.

Decision makers must be aware of three points when using frequency information provided by statistical analysis.

- Statistics need to be put into the context of the time and the place of the situation under consideration. For example, an accident at a chemical plant sited in a sparsely populated area may have affected very few people but this does not imply that a similar occurrence in a residential suburb would affect only a few people.

- The frequency derived by this method is the 'average' frequency, which may have little relevance to the particular case being considered. For example, the frequency of a component failure at a chemical plant could be calculated by analysing the past performance of all identical components, yet the frequency could vary as the plant becomes old, or when the plant begins operations and construction faults cause component failure.

- The accuracy of the risk estimate depends on the reliability and completeness of the data on past events.

Further analysis of the frequency indices can be used to produce frequency versus consequence graphs. From these graphs return periods for certain hazardous events can be calculated. Return periods are usually described in terms of expecting one event in a certain time period, such as a one in 10-year event. The return period information can be used to identify a level of risk that is acceptable, or at least a level of risk that decision makers should aim not to exceed.

Statistical analysis of past events is commonly used in situations where there is a well established data base for a particular event, such as the chance of an industrial component failing when similar components have been in use in many situations for a number of years. When there is a lack of established data extrapolation is used.

6.2 Extrapolation techniques

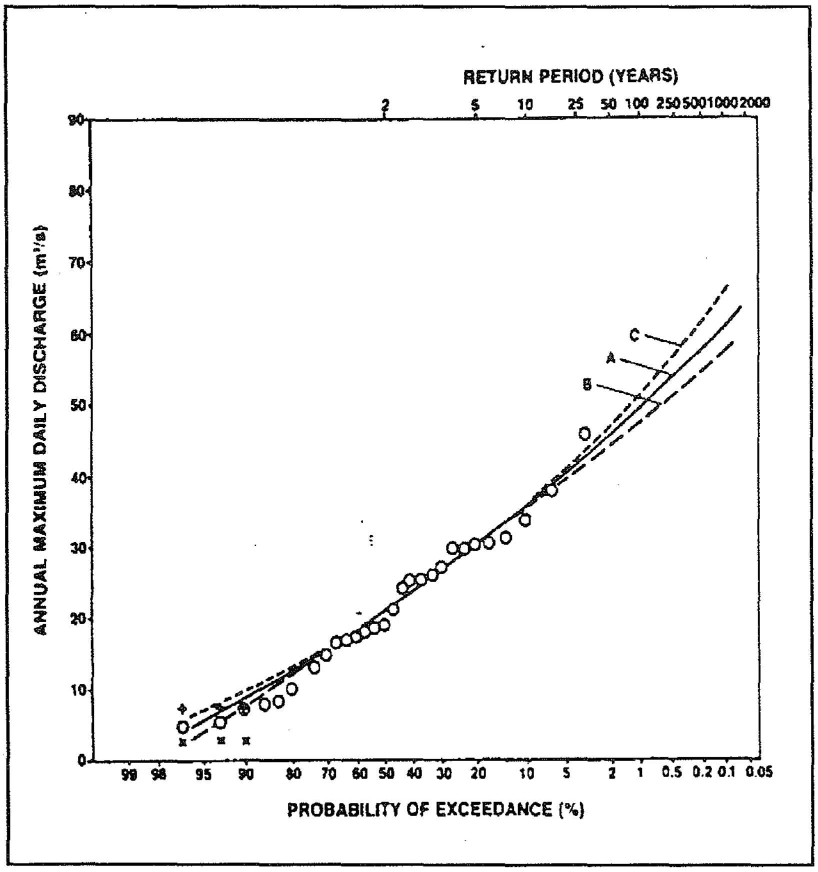

Figure 4: Extrapolation of flood frequency data. The data used to generate curves B and C are slightly altered (shown as crosses) which changes the extrapolations (adapted from Klemes, 1986).

Extrapolation techniques are a variation on statistical analysis of past events. They are used where there are past data on events of lesser consequence but there are no data on 'extreme' events. The probability of an extreme event is estimated by extrapolating from the probabilities of less extreme events.

The frequency derived using extrapolation techniques may not be reliable for two reasons.

- Extrapolation techniques rely on the principle that extreme events are caused by the same physical mechanisms and processes as less severe events. However, extreme events may have different causes from normal events.

- Small errors in the data can result in large errors in the extrapolated frequency (Figure 4).

Extrapolation techniques have been used extensively to assess risks from 'natural' events such as flooding and high winds. At times these techniques have also been used to establish the probability of failures in the components used in industrial plants. Because this technique is used often and affects planning, for example the positioning of hazardous waste stores in relation to the hazard from flooding, decision makers need to be aware of its shortcomings.

6.3 Event tree analysis

Event tree analysis is used when a hazardous occurrence has many possible causes. This type of analysis is used when there are no previous cases of a hazardous occurrence and it is not possible to extrapolate from 'small-magnitude' events to 'large-magnitude' events.

The technique involves systematically analysing all possible failures that could combine in a **sequence** to create a hazardous occurrence. These sequences of events are arranged by the analyst into a logical 'tree' structure with each branch describing a basic event (Figure 5). The final result is a frequency based on the principle that a combination of individual events must happen in sequence to trigger a hazardous situation.

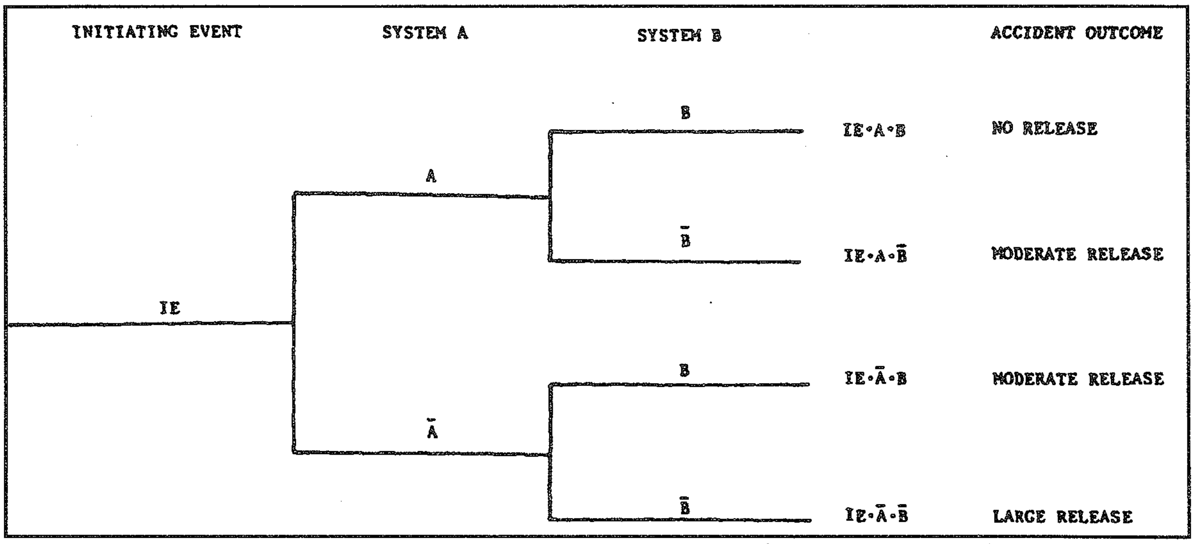

Figure 5: Event tree for a hypothetical nuclear plant (adapted from Vesely, 1984).

Event tree analysis is commonly applied in engineering situations. It is particularly relevant when analysing the frequency of a catastrophe occurring from failures in complex technical structures such as petrochemical plants.

The reliability of a frequency derived using event tree analysis depends on the accuracy of two separate assessments. Firstly, all sequences of events that lead to a catastrophe must be correctly identified. Secondly, the chance of an individual event happening must be accurate. In reality, these conditions may not be met and event tree analysis will not always provide an accurate estimate of the chance of an outcome happening.

While the frequency estimate may not be particularly meaningful to decision makers (due to uncertainty), event tree analysis is very useful to others, particularly engineers and industrial managers. The technique can be used to identify single events that have a comparatively high chance of occurring and steps can be taken to reduce the chance of these events happening.

6.4 Fault tree analysis

Fault tree analysis is similar in style to event tree analysis. It is used to provide a probability of a hazard occurring and is commonly used in industrial situations. However, it differs from event tree analysis in that it starts by considering an undesired event, then **traces back** the different causes that can lead to the event. Event tree analysis, on the other hand, works through causes **towards** an event.

Like event tree analysis, fault tree analysis uses certain assumptions that may not always be reliable. This means that the accuracy of the probability is questionable.

The results from both event and fault tree analysis can be applied in two ways. Firstly, the numerical probability may be used as a criteria to allow a project to proceed, however, we do not recommend this approach because the probability may not be accurate. Secondly, the relative likelihood of the cause of an event can be determined. Comparing probabilities is the useful feature of these two approaches because high probability causes of failure can be targeted and the chances of a hazard occurring can be reduced. Thus, the strength in these related techniques lies in providing **comparative** rather than **absolute** risk estimates.

7 Qualitative risk assessment

Compared to quantitative techniques, qualitative approaches can allow for a greater range of risks to be included in the risk assessment process. Qualitative approaches are likely to be used extensively if the community becomes involved in the decision-making process because communities often place values on the environment that are difficult to quantify. Qualitative **techniques** have only recently become widely used by risk analysts and decision makers; new techniques are still being developed and older techniques are still being refined. Therefore, this section tends to describe general approaches rather than specific techniques.

There are four main types of qualitative risk assessment approach:

- the decision-analytic technique, which extends technical assessment into an area of acknowledged (by technical experts) subjectivity,
- the risk-perception approach, which identifies the perceptions of risk that various groups have,
- the precautionary approach, which promotes caution, and
- the policy-analytic approach, which can be used to devise a framework that incorporates all risk assessment techniques.

7.1 The decision-analytic (weighted) assessment[8]

The decision-analytic technique lies inbetween the purely quantitative and qualitative approaches. This technique can incorporate a wide range of assessments, not just quantitative. It makes explicit acknowledgement and use of value judgements.

This technique uses the process of ranking to determine the importance of different risks. 'Significant' outcomes or probabilities can be given increased 'weighting' by changing their position in the list of rankings. Magnitudes and probabilities do not need to be determined quantitatively: they can be assessed in the terms 'large' or 'small'. Risk assessment information is provided as a list of risks that are ranked according to their severity.

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8. This type of technique was used when assessing risks in the Rosebank Peninsula Area, Auckland, which is described in Section 8.1 of this publication.

In many cases, outcomes and probabilities are ranked separately and a scoring system is used to combine these into a 'risk', in the form of a 'score'. Scoring methods can be developed to meet the specific nature of a situation and can be complex. Scoring systems are flexible and adaptive.

Outcomes are ranked according to the effects they have on the environment. Different ranking methods can be devised for different situations. In situations where certain features within the environment have different values, for example a protected natural area as one feature and exotic forest as another, the effects of outcomes on each feature can be qualitatively assessed and a list of ranked outcomes is made for each environmental feature. Many groups can be involved in ranking and selecting the important features including experts and members of the community.

The probabilities of outcomes happening are similarly ranked. Quantitative and qualitative information about probabilities can be combined. For example, human error might be included in a quantitative estimate of probability by moving that probability higher up the list of ranked probabilities.

Renn (1985) outlines the following characteristics of the decision-analytic technique:

- it regards risk as a subjective mental construction (i.e. perception) about specific outcomes, events or actions,
- the context in which the decision is made is considered to be of primary importance; thus decision makers rather than technical experts can decide what is important to a **particular** situation (context),
- probabilities and preferences are deliberately derived from subjective judgements, intuition, speculation and other sources of knowledge, as well as from technical analysis,
- it is useful for establishing favoured options (because it ranks options), however the options analysed **must** relate to the same problem,
- the benefits and costs (utility) of each option to the participants is regarded as important, so attitudes that help or hinder this utility can be incorporated into the analysis, for example an individual participant's aversion or proneness to taking risk,
- many dimensions of the risk problem can be included, for example risks to spiritual values,

- the problem of human interaction with the source of risk, for example whether or not people will take notice of warning signs or information leaflets, and the subjective probability of human failure can be more readily addressed than in technical analyses, and
- the nature of the analysis can vary from situation to situation, for example, different methods might be used to assess the values that are important to different types of community, such as rural or urban.

The decision-analytic assessment technique has advantages for the decision maker compared with quantitative techniques. It can take account of the subjective nature of risk. This technique can allow the sectors of society affected by the risk to have an input into the assessment process. It can legitimise policies in the face of criticism, because no single type of analysis (e.g. technical) is used as the sole criterion for a decision. In effect this technique broadens the information base upon which a decision is made.

This technique also has disadvantages. It does not always make allowance for the influence that technical analysts have on the decision-making process. This influence can occur in a number of ways, for example a technical expert may present a convincing analysis but may neglect to mention inherent uncertainties that would weaken the analysis. Furthermore, there is an assumption in the decision-analytic technique that decision makers are only interested in making rational decisions, whereas often decisions have political implications; decisions made may hence seem irrational to some. The decision-analytic technique may not focus on these types of issues yet they can have a large influence on the final decision.

7.2 Risk perception

This approach is based on assessing the criteria that are important to those who are exposed to the risk. It recognises that different groups have different appreciations of risk.

Gough (1990) identifies four methods for determining perception of risk:

- revealed preferences,
- expressed preferences,
- implied preferences,
- natural standards.

The **revealed preference** method is based on the assumption that by trial and error society has arrived at a nearly optimal balance between the risks and benefits associated with an activity. However, society may not operate currently at an optimal level of risk. Past decisions might have been the result of poor public policy making, indifference from the community, lack of information, or 'old' values that have changed. New evidence may come to light that alters risk assessments, for example agricultural chemicals that were once thought to have acceptable risks have been banned due to unforeseen outcomes, such as the accumulation of toxic residues.

Thus, the revealed preference method has many flaws:

- it does not allow for changing societal values,
- the method assumes that people have full information and use it optimally,
- it assumes that decisions in the market place are 'right', and
- the method ignores important questions about equity and the access that groups have to the decision-making process.

The main advantage of this approach is financial. Existing data can be used to gain some idea of the risks that society currently accepts, negating other costly and difficult methods of assessing the level of risk that society is willing to accept, such as the methods discussed below.

The **expressed preference** approach takes the view that it is meaningless to compare risks in different activities, as technical experts have tended to do in the past. A level of risk that is acceptable needs to be determined for each and every situation involving risk, because society perceives different risks in different ways. This approach assumes that there is no one single level of acceptable risk that can be applied to all situations.

The expressed preference approach can be used to establish **values** that are violated. Quantitative (technical) techniques do not accommodate societal values readily (other than death) nor does the decision-analytic technique (but to a lesser degree). Evidence from both overseas and New Zealand suggests that values are important in a community's assessment of risk, and that values can influence the identification of an acceptable risk.

There are problems with the application of the expressed preference approach. Firstly, the approach assumes that many people have the **same** perception of risk, which means there are difficulties dealing with large variations in risk perception within sample groups.

Secondly, to canvass public opinion, innovative survey techniques are required, which can be difficult to implement and costly.

The **implied preference** method determines society's preferences by considering all aspects of the institutions that have been set up to deal with risk issues in the past. For example, Court or Planning Tribunal decisions are often used in New Zealand as precedents and these may be interpreted as levels of risk that society is prepared to accept for certain activities. Proponents of this method consider that the decisions made in the past do not represent the optimum situation, but regard the attempts as the best to date.

Unfortunately, institutions and their associated activities are not entirely consistent and are continually changing. For example, all levels of government in New Zealand have been restructured and agencies responsible for assessing certain risks have been abolished or had their operating structure changed. The implied preference method, therefore, can result in time-consuming and tortuous interpretation of information.

The **natural standards** approach takes the view that nature provides the best indication about environmental risk. It assumes that whatever the environment has tolerated in the past is tolerable in the future, and provided that human activities do not alter natural systems too much, the environment is not subject to excessive risk. The simplicity and logic of this approach make it seem like an appealing method for assessing environmental risk. However, it does have a major problem. This approach is open to the subjective selection of particular versions of reality i.e. perceptions play an important role in this approach. For example, technical experts may argue that a certain chemical poses no hazard because it has always been present in the environment, while other people may argue that the concentrations of the chemical are in excess of 'natural' levels and that this could pose a significant hazard.

Perceptions of risk vary from situation to situation, group to group and individual to individual, and can depend on the method used to elicit the information. However, some consistent points concerning people's perceptions of risk have emerged that decision makers can be aware of (Renn, 1985):

- people react differently to unfamiliar and familiar risks,
- people are happier to accept risks over which they feel they have some control, compared with those that they believe they have no control over,
- whether or not the risk is perceived as being a 'sensible' risk is often important,

- how 'dreaded' a risk is will often affect people's perceptions,
- the extent to which the hazard will cause harm, both to life and values, is important to people, even when the chance of the hazard occurring is small,
- how well people can imagine the cause of an accident will affect their perception, and
- the impact of the need to enforce excessively strict and far-reaching precautions and regulations will affect people's attitude to risk.

7.3 The precautionary approach[9]

The precautionary approach gives the benefit of the doubt to the environment. While this may appear to be a simple and reasonable criteria against which to evaluate risk, its application can cause problems. The major difficulty lies in determining when and where uncertainties and risks lie in a decision. For example, technical experts may state with some certainty that a substance will be harmless when released into the environment, but some years later new evidence may come to light that shows the substance to be unsafe.

The precautionary approach is very new and has been used in only a few applications. It appears to provide useful information about situations where damage to the environment may not become apparent for many years after an event has happened, or when uncertainties are large. For example, the International Joint Commission[10] (IJC) have adopted an anticipatory approach as a policy. As an anticipatory action, the IJC is now considering banning the use of all chemicals containing organo-chlorines in the catchments of the Great Lakes due to the length of time these chemicals remain active in the ecosystems and the potential these chemicals have to cause health problems to many different species including humans. Because of lack of experience with this approach the techniques for its implementation in New Zealand need to be considered and developed.

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9 Also known as the anticipatory or preventative approach.

10 The IJC has responsibility for managing the water resources of the Great Lakes in North America.

7.4 The policy-analytic approach

The policy-analytic approach is a tool that can be used by decision makers to synthesise all risk assessments into one framework. It can be used to subjectively, but defensibly, determine the type of assessment that will carry most weight.

The policy-analytic approach to risk assessment emphasises process rather than outcome. It focuses on the social and political process of decision making and can be used to determine the effects of various influences on the risk assessments, such as institutional constraints, communication interactions, power interplays, and the distribution of power among the participating groups. On the basis of information provided by policy analysis, the risk assessment process can be changed to meet specific criteria, such as the need to increase the input from specific participants, or the need to hasten a decision.

The strength of the policy-analytic approach is that it explores the social and political environment in which a decision takes place. Environmental risk decisions tend to become socially and politically oriented and the policy-analytic approach can 'enlighten' decision makers as to how an overall assessment of a risk was **really** made, and how this information was **actually** used. For example, policy analysis may provide insights into how risk assessments associated with the Clyde Dam were made, and how the resulting information was handled.

On the basis of the insights gained by policy analysis decision makers can change the nature of risk assessment processes. For example an assessment process can be altered to allow for increased input from disadvantaged participants.

8 Situations involving environmental risk assessment in New Zealand

This section provides some examples of situations involving environmental risk assessment in New Zealand. It outlines the approaches and types of information that have been used by decision makers. The aim of this section is to relate the theory in the preceding sections to real situations.

While the examples given in this section generally concern large industrial projects, it should be remembered that small scale developments and activities can also pose a significant risk to the environment. Both the individual effects and the cumulative effects of small scale projects need to be assessed for the risk they pose; for example the combined effects of land clearance, wetland drainage and contaminated runoff may subject a stream ecosystem to risk, but this does not normally occur. Usually it is only the 'big' projects that are assessed for environmental risk.

8.1 Rosebank Peninsula, Auckland[11]

The Rosebank Peninsula is located in Western Auckland and lies in the southern part of the Waitemata Harbour. It is approximately four kilometres long, is zoned industrial and is the site of heavy industries, many of which use hazardous substances.

In 1988, the Auckland City Council commissioned a risk assessment study of the area, in response to a number of hazardous incidents that had occurred in recent years. There was public concern that neighbouring environments (including residential areas) were being subjected to excessive risk.

The initial stages of the study took a qualitative approach along the lines of the decision-analytic technique. Subsequently, detailed quantitative risk assessments were carried out on the risks that were ranked highly.

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11 See Geological Consultants of New Zealand (1989) in suggested reading list.

In the qualitative assessment phase, the environment was broken into three features or 'categories':

- the living environment (e.g. Waitemata Harbour),
- property (e.g. housing, industrial premises),
- people (e.g. worker, members of the neighbouring residential community).

For each environmental category the **effects** of potential outcomes were divided into different groups. The risks were assessed (Figure 6) by experts who were familiar with industrial premises. The experts used a 'commonsense' approach (i.e. their perception) to estimate levels of risk in qualitative terms. In a similarly qualitative manner the experts assessed the relative contributions that different **activities** made to the risks in an environmental category (Figure 7).

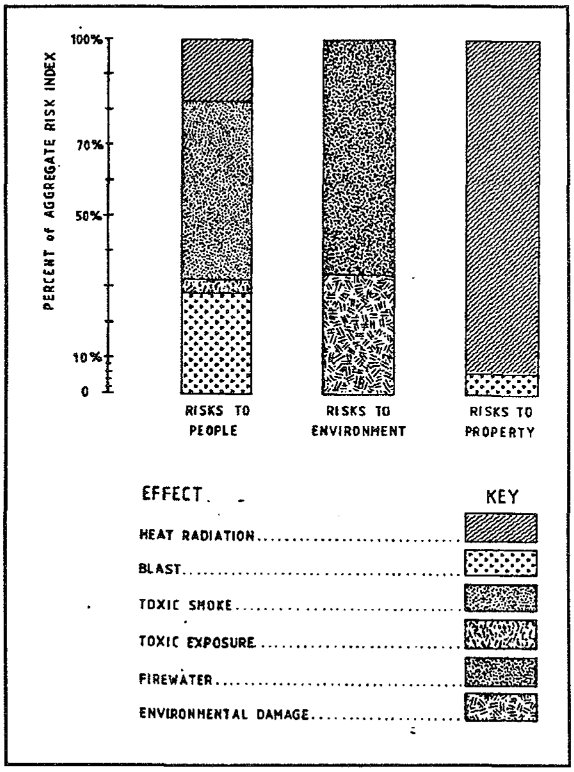

Figure 6 Different hazardous effects and their relative risk-contribution to three environmental categories (Source, Geological Consultants of New Zealand, 1989).

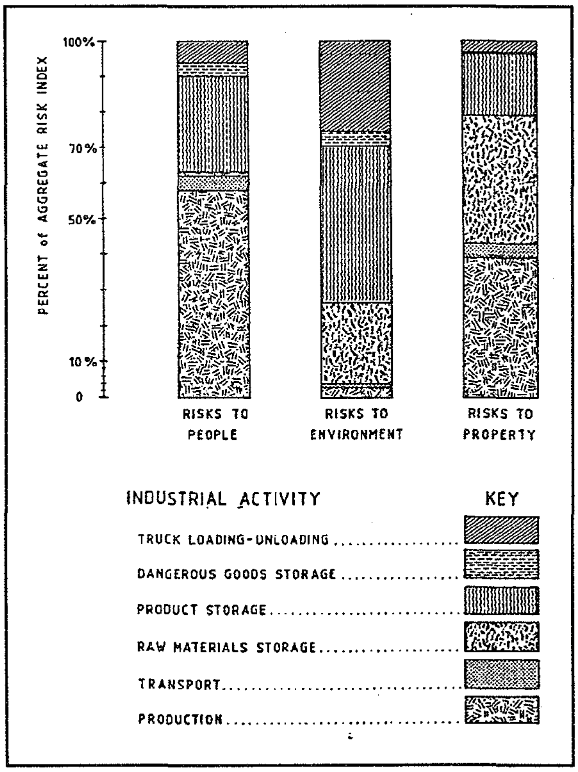

Figure 7 Activities which subject three environmental categories to risk (Source, Geological Consultants of New Zealand, 1989).

Experts made quantitative assessments of the risks that were ranked as being 'large'. The quantitative risk assessments were made mainly on the basis of statistical analysis of past events. Risk assessments of specific scenarios, such as fires and the associated hazard posed to the environment by contaminated firewater, were made on a 'what if' basis similar in style to a combination of event and fault tree analysis.

Experts determined acceptable quantitative risk levels using a variety of methods, including subjectively selecting an "appropriate benchmark" and choosing objectives like "... the houses along the main roads on the Peninsula should not have their risk of fire significantly increased by transport of hazardous goods."[12]

Throughout this study assessments were made by experts. There was very little input from the neighbouring residential community. Many of the assessments, including the acceptability of risks, were based on experts' perceptions.

On the basis of the information provided by the risk assessment a rationale for reducing risk was developed. Recommendations were aimed at management of industry, statutory authorities and emergency services.

8.2 Western reclamation petrochemical storage area, Auckland[13]

The Western Reclamation Area is close to 'downtown' Auckland. It extends into the Waitemata Harbour and is used to store petrochemicals. The area was the landing point for petrol supplies to the Auckland area but, with the construction of a pipeline between Auckland and Marsden Point, the amount of petrol being shipped has reduced.

A risk assessment study was commissioned by the Auckland City Council, Harbour Board and Regional Authority in 1988. These agencies recognised that handling-facilities in the area were changing (due to pipeline construction) as were the social and environmental conditions including social expectations. Furthermore, it was recognised that an increasing range of potentially hazardous chemicals were being landed. With all these changes, the three agencies agreed that it was necessary to improve management techniques in order to attempt to reduce the risk or hazard. This primarily involved assessing the risks.

The approach taken to the risk assessment study was mainly quantitative and predominantly used fault tree analysis. The study looked at single and cumulative events

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12 Quotations taken from the 'Rosebank Peninsula risk assessment study'.

13 See New South Wales Department of Planning (1989) in suggested reading list.

The approach taken to the risk assessment study was mainly quantitative and predominantly used fault tree analysis. The study looked at single and cumulative events and considered a wide range of issues, including safety standards. Some of the analysis was very detailed, for example the performance of individual fuel control valves was analysed.

The risk assessment was carried out by technical experts with little input from 'the public'. The assessment acknowledged that purely probabilistic (quantitative) approaches were generally of limited value to the decision-making process, thus the assessment incorporated some qualitative aspects with the quantitative analysis. For example:

- the process of identifying hazards was undertaken by on-site auditing and surveys that assessed activities like the operation of safety equipment i.e. the assessment contained value judgements made by experts,
- ranking systems were used to determine the most severe incidents,
- the assessment study recognised that the public is concerned with potential hazards regardless of the probability of the hazard occurring.

The result of the assessment was a quantitative, contoured 'risk map' (Figure 8), which can provide information for planning further development near the installation. Methods for reducing risk were also suggested.

8.3 Oil drilling application, Sugarloaf Islands Marine Park, Taranaki[14]

During 1989, the oil exploration consortium 'TCPL Resources Limited' sought rights to drill for oil in the Sugar Loaf Islands Marine Park. Some sections of the community became concerned that a major drilling accident would have disastrous consequences for a regional 'taonga', and the issue quickly became one of risk. In the community's mind, the negative consequences of an accident were very important considerations, even if the probability of occurrence was small.

The exploration consortium released an initial report outlining the proposed drilling programme. This report called for submissions and a second report that addressed issues raised in the submissions was released. Neither report contained a comprehensive environmental risk assessment of the proposal.

[14] The information in this section has been obtained from newspaper articles, reports commissioned by TCPL Resources Limited, and communication with agencies involved in the consent process.

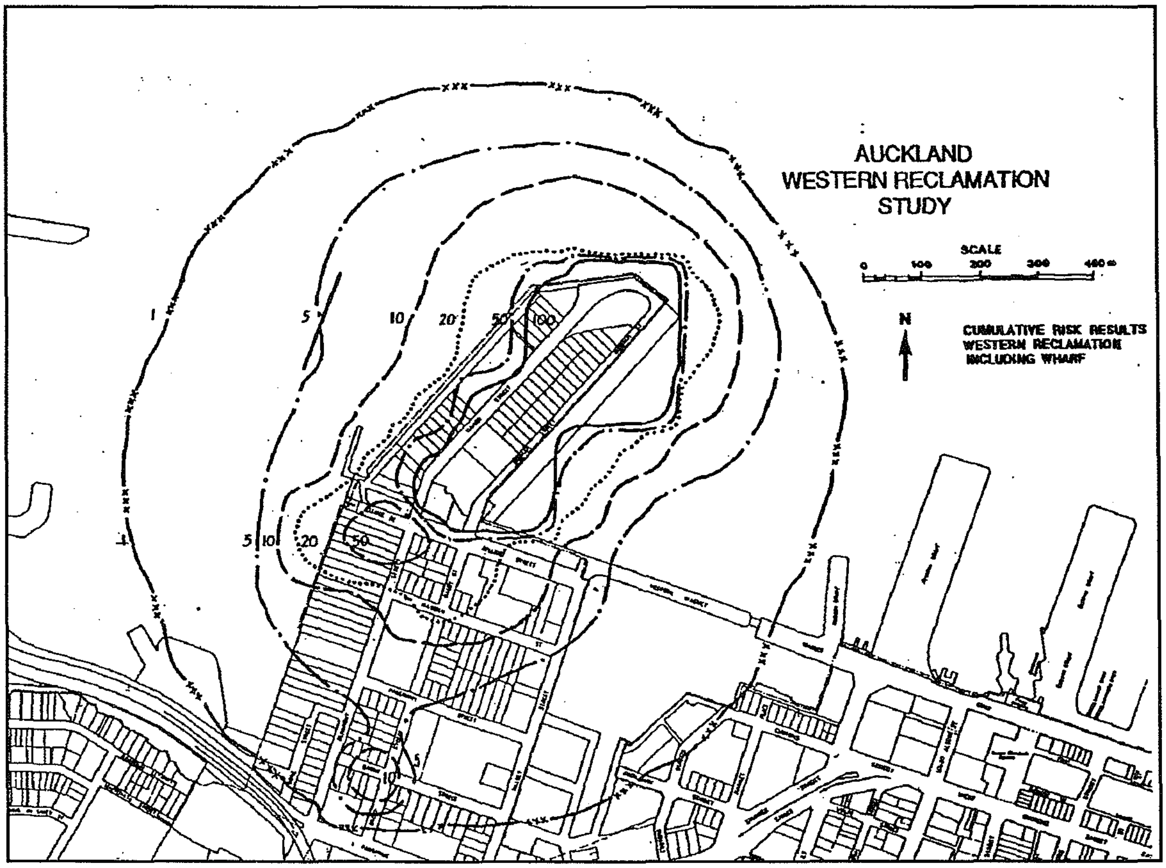

Figure 8 Risk map for the Western Reclamation Area. The risk contours are in units of millions/per person per year (Source, New South Wales Department of Planning, 1989).

The release of the second report did little to reduce the community's unease about the proposal. The New Plymouth City Council considered that some matters of concern were such that the drilling programme should not proceed unless ways of overcoming these matters could be achieved. Community groups continued to oppose the proposal and a protest march was held in New Plymouth which attracted around 200 people.

The drilling application required consents under many different pieces of legislation. The statutory process did not clearly define whether environmental risk could be raised as a valid objection. Consequently, there was debate at the time as to how environmental risk should be addressed.

At the time of writing this guide, the issues associated with the drilling application had not been resolved.

8.4 Herbicide use in the Kaeo area, Northland[15]

In the Kaeo area, Northland, agriculture was the predominant landuse. The area had a thistle/gorse problem and farmers often used hormonal sprays such as 2,4,5,-T and 2,4-D as a means of control. In the 1970s and 1980s, horticulture developed in the region and horticulturalists perceived a significant risk to their crops from the agricultural sprays.

Horticulturalists brought the issue to the attention of the farmers. The farming community was generally willing to acknowledge the risks and a meeting was held between the two groups over morning tea. An informal assessment of risk was made by those involved in the issue and both the farmers' and horticulturalists' perceptions of risk were given validity. The only 'technical expert' present was a noxious plants officer who gave an outline of the sprays to use, when to apply them, and generally steered the gathering. The meeting led to an assessment of the risks that both groups accepted. On the basis of the assessment, a workable and practical management strategy for agricultural spray application was agreed upon and implemented.

This very informal method of assessing risk, which involved lay-person's perceptions, is currently being used as a basis for managing risks from agricultural sprays in the grape-growing area around Martinborough, Wairarapa.

[15] The information in this section has been obtained through personal communication with D. Gibbs, formerly of Kaeo, now farming near Martinborough.

9 Summary

Four points emerge in assessing risk.

- All assessments of risk contain subjective elements, including technical assessments.

- There is no single level of risk that society finds acceptable. The risks that society is prepared to accept or tolerate will vary from situation to situation.

- The community needs to be involved in making an assessment because it is the community that is most affected by a risk. Therefore, environmental risk assessment involves community participation as well as expert participation. Because members of the community need to be informed, risk information must be readily accessible and presented in a way that lay-people can understand.

- There is no single 'correct' way of assessing environmental risk. While there is a general process that can be followed, specific techniques used within the process will vary depending on the situation. Risk assessments will often require the use of many different approaches and techniques.

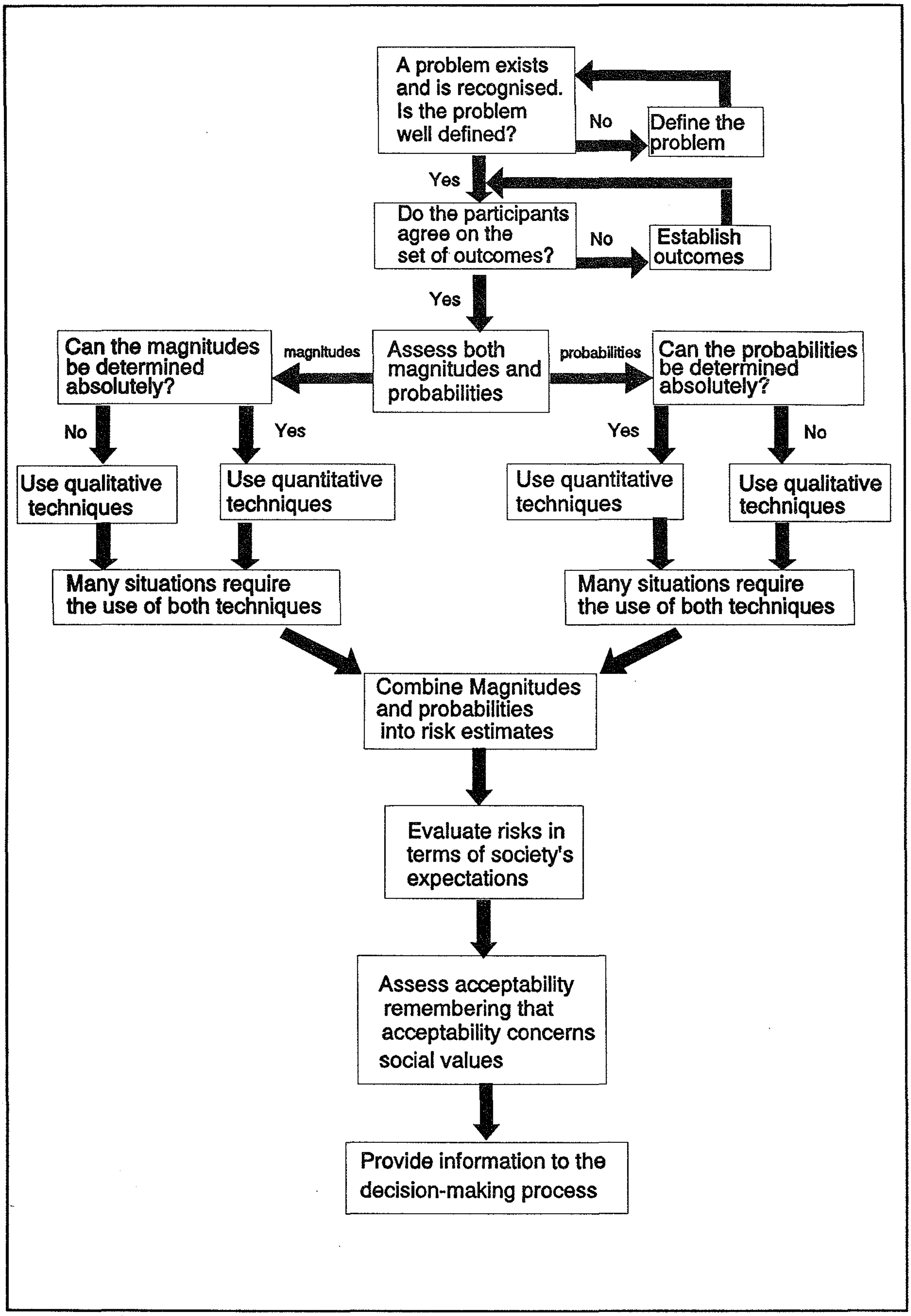

Figure 9 Assessing environmental risk.

Figure 9 illustrates the process of assessing environmental risk. It expands upon the basic risk assessment process illustrated in Figure 4.

9.1 Suggestions for selecting risk assessment techniques and approaches

Many risk assessments use a mixture of qualitative and quantitative approaches. The use of certain techniques or approaches depends on the situation surrounding a particular assessment. Some points to help readers select specific risk assessment techniques and approaches are now outlined.

Quantitative (technical) techniques are of most use when the issues are clearly defined and are agreed to by all participants, with the caveat that affected groups have fair access to the decision-making process.

The following are criteria for selecting specific quantitative assessment techniques.

- **Statistical analysis** of past events can be used when a long period of record is available on identical situations involving risk, for example the rate of failure of a particular component in an industrial plant.

- **Extrapolation** may be used when a comparatively 'short' period of record exists but 'extreme' events have not occurred. To provide accurate information the extreme event must be caused by the same physical processes and mechanisms as less severe events. This technique is often used to provide information about 'natural' hazards such as flooding.

- **Event** and **fault trees** are used to determine risks in complex technical structures when a combination of events must occur in sequence to produce a hazard, for example in industrial plants. These techniques are useful for determining the relative probability of failure between different components in an industrial plant but may not provide an accurate assessment of the chance of a hazardous occurrence because the probabilities provided by these techniques do not normally take into consideration 'unusual' causes such as human error.

Qualitative approaches are most useful when issues are not clearly defined, or participants cannot agree on what the issues are when there is limited quantitative data available, or when specific values that are important to a community are threatened.

The following provides a summary of when particular qualitative approaches and techniques are most useful.

- **Decision-analytic technique:** Most useful in situations where technical and social factors must be combined and a range of options are being considered.
- **Revealed preference:** Has many problems and should be used with extreme care.
- **Expressed preference:** Useful when values that are important to a community may be compromised by a risk.
- **Implied preference:** When case histories exist and are **relevant** to the situation under consideration, this approach can be used.
- **Natural standards:** Is useful when the concentration of substances or processes in the environment might change as a result of an action.
- **Precautionary approach:** Useful when a hazard may be realised many years after an event has happened, or when uncertainties are large, or any situation where prevention is better than the cure. This approach may be useful for assessing risks from human activities such as groundwater contamination or the use of pesticides that produce toxic residues.
- **Policy-analytic approach:** Is a tool that a decision maker can use to provide himself or herself with 'insight' into the risk assessment process. For example this tool may be used to analyse the level of input that various groups have to the assessment process, allowing the decision maker to take into consideration the different skills and ability that the participants have.

Many qualitative approaches make use of input from groups within the community. Techniques to allow **community participation** in the assessment process vary depending on the nature of a community. For example a decision maker could enable a community to express their preferences by meeting community leaders, or randomly surveying members of a community. Techniques for involving communities in decision-making processes are being developed in an ongoing research programme at the Centre for Resource Management.

Suggested further reading

This section combines both a reference list and a bibliography of useful readings. A brief description of each item of reading material is provided to help the reader select literature that suits their needs.

British Medical Association, 1987. *Living with risk.* Wiley Press. *[A clear descriptive outline of the history, nature, measurement and types of risk. Easy reading.]*

Conrad, J. (Ed.) 1980. *Society, technology and risk assessment.* Proceedings of conference held at Frankfurt. Academic Press. *[A detailed book. Considers at some length the various risk assessment techniques. A key text.]*

Conservation Foundation, 1987. *Risk communication.* Proceedings of Conference on Risk Communication held in Washington DC, January, 1986. Davies, J.C, Covello, V.T., and Allen, F.W. (Eds) Conservation Foundation. *[Represents the 'coming of age' of risk communication. The information is clearly presented and this text provides useful background reading about risk issues that involve public participation.]* **Copies** available from: The Conservation Foundation, 1250 Twenty-fourth Street, NW, Washington, DC 20037.

Department of Planning, Sydney, 1989. *Environmental risk impact assessment guidelines.* Hazardous Industry Planning Advisory Paper No. 3. *[This document provides guidelines on hazard analysis and risk assessment. It takes an integrated approach to safety planning and looks at the wider context of siting hazardous industries and building safety controls into their design. This paper is specifically oriented to risks associated with industrial complexes.]* **Copies** available from: The Information Branch, Department of Planning, Ground Floor, 175 Liverpool Street, Sydney NSW 2000.

Department of Planning, Sydney, 1990. *Risk criteria for land use safety planning.* Hazardous Industry Planning Advisory Paper No. 4. *[This paper provides guidelines which local councils, development proponents and the community can use when assessing risk from industrial development.]* Copies available from: The Information Branch, Department of Planning, Ground Floor, 175 Liverpool Street, Sydney NSW 200

Douglas, M. and Wildavsky, A. 1982. *Risk and culture.* University of California Press. *[An essay on the selection of technical and environmental dangers. Descriptively written and very readable. Analyses the effect of the 'cultural context' on risk issues.]*

Fischoff, B., Lichtenstein, S., Slovic, P., Derby, S.L. and Keeney, R.L. 1981. *Acceptable risk.* Cambridge University Press. *[Examines approaches to acceptable risk. Aimed at a wide-ranging audience. Readers are not expected to have mathematical or technical knowledge.]*

Geological Consultants of New Zealand, 1989. *Rosebank Peninsula risk assessment study.* Commissioned by the Auckland City Council. *[A study of the environmental risks posed by an industrial area in Auckland.]*

Gough, J.D. 1988. Risk and uncertainty. *Information Paper No. 10.* Centre for Resource Management, Lincoln College, Canterbury. *[This publication provides an overview of the risk literature, concentrating on general approaches to risk analysis and risk assessment.]*

Gough, J.D. 1989. A strategic approach to the use of environmental impact assessment and risk assessment within the decision-making process. *Information Paper No. 13.* Centre for Resource Management, Lincoln College. *[Consideration is given to the need for environmental impact assessment and risk assessment procedures. A generalised approach is suggested for dealing with public and private proposals where consent, and therefore assessment, procedures are required. This report does not outline specific approaches.]*

Gough, J.D. 1990. A review of the literature pertaining to "perceived" risk and "acceptable" risk, and methods used to estimate them. *Information Paper No. 14.* Centre for Resource Management, Lincoln University, Canterbury.

Hertz, D.B. and Thomas, H. 1983. *Risk analysis and its application.* Wiley Press. *[Deals with many aspects of risk assessment. Has a strong emphasis on the financial and economic approaches to dealing with risk issues.]*

International Joint Commission, 1978. *The ecosystem approach.* Published by the Great Lakes Science Advisory Board, Ontario. *[Seeks to combine social and environmental*

Fisheries, Great Lakes Laboratory for Fisheries and Aquatic Sciences, Canada Centre for Inland Waters, PO Box 5050, Burlington, Ontario, *Canada L7R 4A6.*

Klemes, V. 1986. Dilettantism in hydrology: transition or destiny. *Water resources Research 9:* 22. pp.177S-188S. [This paper explores the 'unsatisfactory state of hydrology', including problems in the area of flood frequency analysis and the techniques used (e.g. extrapolation).]

Mazur, A. 1981. *The dynamics of technical controversy.* Communications Press. *[Provides general principles on dealing with technical controversies, and considers the types of data required to advance the understanding of issues. Discussion is almost entirely limited to affairs in the United States, but has some application to New Zealand situations.]* **Copies:** Communications Press Inc., 1346 Connecticut Avenue, NW, Washington DC, 20036

New South Wales Department of Planning, 1989. *Western reclamation area risk assessment study,* Auckland, New Zealand. *[An assessment of the risks associated with petro-chemical storage facilities situated in close proximity to downtown Auckland. Report commissioned jointly for Auckland City Council, Auckland Harbour Board and Auckland Regional Authority.]*

Rip, A. 1985. Experts in public arenas. *In:* Otway, H. and Peltu, M. (Eds) *Regulating industrial risks.* Butterworths Press (printed at the Cambridge University Press). *[This chapter examines myths about scientific expertise and suggests a more realistic approach to the practice of giving and receiving expert advice. The entire book provides useful information, especially a chapter by Ortwin Renn, titled "Risk analysis: scope and limitations.]*

The Royal Society, 1983. *Risk assessment.* Report of the Royal Society Study Group. *[Provides a practical and useful description of all aspects of environmental risk assessment. A comprehensive document.]* **Copies** available from: The Royal Society, 6 Carlton House Terrace, London, SW1Y. 5AG

Vallentine, J.R. (undated). *The case for phasing out organohalogens.* Palter, J. (Ed.). *[Examines the rationale behind a particular anticipatory action.]* **Copies** from: Greenpeace, 185 Spadina Ave, Suite 600, Toronto, Ontario, Canada. M5T 2C6

Vallentine, J.R. (undated). *The case for phasing out organohalogens.* Palter, J. (Ed.). *[Examines the rationale behind a particular anticipatory action.]* **Copies** from: Greenpeace, 185 Spadina Ave, Suite 600, Toronto, Ontario, Canada. M5T 2C6

Vallentine, J.R. and Hamilton, A.L. 1987. Managing human uses and abuses of aquatic resources in the Canadian ecosystem. *In:* Healy, M.C. and Wallace, R.R. (Eds) *Canadian Aquatic Resources.* Canadian Bulletin of Fisheries and Aquatic Sciences, No. 215. Outlines anticipatory approaches in a clear way. **Copies:** Department of Fisheries, Great Lakes Laboratory for Fisheries and Aquatic Sciences, Canada Centre for Inland Waters, PO Box 5050, Burlington, Ontario, Canada L7R 4A6.

Vesely, W.E. 1984. Engineering risk analysis. *In:* Ricci, P., Sagan, L. and Whipple, C. (Eds) *Technological risk assessment. [This paper provides a useful description of the technical approaches to risk assessment.]*

Glossary

ACCEPTABLE RISK
risk that is judged by society to be acceptable

ACCEPTED RISK
risk that is apparently accepted by society, for example, driving a car

ACTUAL RISK
scientifically calculated or experienced (usually statistical or predicted risk)

FREQUENCY
a measure of the number of events that have occurred in some past time period, divided by the time period (i.e. a number per time period)

HAZARD
a harm or negative outcome

PERCEIVED RISK
risk as seen intuitively by individuals or societal groups

PREDICTED RISK
risk as measured by systems models using historical data

REAL RISK
risk that will be determined by future circumstances, and that therefore cannot be measured

RISK
probability of the occurrence of harm compounded with the magnitude of a harmful event

RISK ASSESSMENT
risk determination and evaluation

RISK DETERMINATION
risk identification and estimation

RISK ESTIMATION
the calculation of the probability of occurrence and the magnitude of the possible outcomes

RISK EVALUATION

the determination of the significance or value of the risk, including study of risk perception and the tradeoff between perceived risk and perceived benefits

RISK FACTOR
something that causes a risk

RISK IDENTIFICATION
the identification of all possible sources of risk and the possible outcomes from particular actions

RISK MANAGEMENT
the making of decisions involving risk and the implementation of these decisions

SAFETY
an action is safe if its risks are judged to be acceptable

STATISTICAL RISK
risk measured statistically using currently available data

UNCERTAINTY
a lack of knowledge arising from changes that are difficult to predict or events whose likelihood cannot be accurately predicted