

Environmental Risk Assessment

An Australian Perspective

Executive Summary

Environmental risk

Environmental risk deals with the probability of an event causing a potentially undesirable effect. Quantitative risk assessment thus deals with statistics, because probability is the mathematical measure of risk, and with hazard assessment which determines the nature of the undesirable effect. The terms have different meanings and different definitions in different areas of study.

Over the past two decades, risk assessment has attained maturity as an engineering discipline assisted by seminal reports by the United States National Research Council and by the Royal Society in Britain. Environmental agencies, principally the US EPA, have embraced it as an objective tool to enable them to set standards, set priorities and provide assistance in decision making. It has long been applied in this way to evaluate the risks to human health arising from radionuclides and chemicals in the environment. Hazard assessment has been used to study natural hazards and assist in preparing for them. The recent application of risk assessment techniques to flora and fauna is being called ecological risk analysis.

The US has a major program using risk assessment to determine environmental priorities at national, state, regional, community and tribal level. Its use in this form is called comparative risk assessment. It involves ranking issues on the basis of their likelihood of occurrence and the magnitude of the actual or perceived consequences.

The means by which risk is managed, the means by which risk is communicated to the public and the consequences of failing to undertake adequate risk assessment or undertaking incorrect risk assessments need to be known and appreciated by environmental practitioners. These issues are seen as an integral part of a quality assured environmental management system.

Methods and results

The approach adopted to the study was based on the following elements:

- I. Reviewing the literature, plus extensive consultation to determine Australian practice, and international best practice, in the application of quantitative risk assessment.
- II. Identifying areas that are of current concern to environmental protection and choosing appropriate case studies for each area.

Each case study deals with an apparently contentious topic and the discussion of the case study seeks to determine whether the contentious aspects of the topic could have been minimised through application of quantitative risk assessment. The areas, identified by the Executive Director of the EPA, and case studies are:

Risk from chemicals and from contaminated sites: Case study — atrazine.

Field trials on their own fail to provide definitive answers to the behaviour of chemicals. They must be integrated with computer modelling, with the results of the field trials being used to calibrate and validate the model. The model provides a predictive tool in situations other than those of the field trial. There is a reluctance to undertake such integrated studies because no model has received official accreditation. This should be done.

Risk to people from development: Case study — Sydney 3rd runway.

This case study identified deficiencies in the standard methods of measuring the impacts of noise.

Risk to the natural environment from development: Case study — setting priorities to investigate uranium mining.

The techniques of comparative risk assessment were used to propose topics for the next four environmental performance reviews to be conducted by the Office of the Supervising Scientist.

Risks of the uncertainty of nature: Case study — climate change.

Present work on climate change is driven by the implicit risk assessment expressed in the precautionary principle. This envisages large adverse consequences as a result of inaction in the face of a possible hazard.

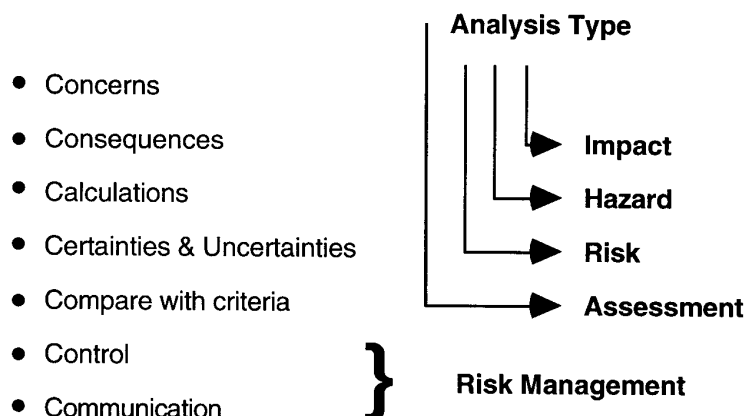
Risk associated with political decision-making: Case study — Coronation Hill.

The Coronation Hill saga highlights the importance of timing. The combination of environmental issues, Aboriginal issues, the timing of elections and leadership disputes led to the failure of the proposal to mine and concern about sovereign risk as an issue in Australian environmental concerns. Time heals. Sovereign risk is no longer perceived to be a risk for miners in Australia.

III The search for a generic framework that can be used for quantitative risk assessment in Australia.

The final choice of generic framework is shown in Figure 1. When the formal methodology of the framework was applied to the question of release of water from the restricted release zone of the Ranger Uranium Mine, the result confirmed that long term land disposal has a 90% probability of exceeding recommended radiation dosages for Aboriginal people living traditional life-styles in the area of land disposal. More significantly, the methodology highlighted that previous research and this analysis all assumed perfect knowledge of the future behaviour of the traditional owners. The fact that this is not known indicates that the Environmental Research Institute of the Supervising Scientist (ERISS) should widen its research to include Aboriginal lifestyles and culture.

Figure 1 Risk Assessment Framework



Implementation

Risk assessment is a tool for informed decision making. The decision facing Australian environmental agencies is whether to introduce a process of formalised risk assessment; and if so, how should it be done and what should be its scope. Any agency that deals with risk assessment needs to be able to deal not only with matters

referred to it, but also to have the freedom to identify issues that may pose future risks. This document is the first step in this process.

The next step will be a conference on risk and uncertainty in environmental management. This conference, designated a Fenner Conference by the Academy of Science, will be held 13-16 November 1995. The final day of the conference will consist of a workshop at which it is intended to undertake a risk-benefit analysis of introducing risk assessment. It is anticipated that the costs are quantifiable, once the scope of the process has been determined.

The important benefits are expected to be:

- transparency of process;
- informed decision making; and
- input to priority setting.

Thus, one purpose of a conference such as this is to decide whether the value of these benefits are likely to exceed the costs of implementation.

The generic framework provides a model for accomplishing the technical aspects of risk assessment.

Application of a quantitative risk assessment requires capabilities in four primary areas:

- (i) a systems analysis capability that can be used for scenario development;
- (ii) technical expertise that can be used to quantify hazards;
- (iii) statistical skills, possibly in conjunction with computer modelling expertise, that can be applied to uncertainty analysis as, for example, in probabilistic modelling; and
- (iv) expertise that can be used to quantify the costs or benefits associated with assessing priorities.

In most cases, quantitative risk assessment will involve the use of computers and the need to obtain or develop appropriate software. There is probably not enough work within one section of the Department to keep risk analysts employed but there should be enough work across the whole of DEST to do so. Examples from within the EPA include chemicals, contaminated sites, EIA reviews, cumulative impacts, urban air quality and Northern Territory concerns.

Overview

1. Environmental risk assessment

The draft Australian/New Zealand Standard on Risk Management (DR 94351) of October 1994 defines risk as follows:

" ... risk arises out of uncertainty. It is the exposure to the possibility of such things as economic or financial loss or gain, physical damage, injury or delay, as a consequence of pursuing a particular course of action."

The concept of risk has two elements, i.e. the likelihood of something happening and the consequences if it happens.

Hazard is an intrinsic property of a substance, which is activated upon an event. To be more specific, consider the risks associated with diving into shallow water. The shallow water itself constitutes a hazard. The act of diving is the event that precipitates the risk. The consequences can range from severe, such as death by drowning to mild, such as cuts and scratches.

Hazard becomes a risk only when there is a finite probability of a manifestation of the hazard. Within this framework, toxicologists define risk as the product of a hazard and its likelihood of occurrence. To make it easy to remember, Environment Canada uses a definition based on the letter E, in which likelihood of occurrence is replaced by entry into the environment so that

$$\text{RISK} = \text{HAZARD} \times \text{ENTRY} = \text{EXPOSURE} \times \text{EFFECTS} \times \text{ENTRY}$$

1.1 Risk analysis and risk assessment

Environmental risk analysis considers the risks to human health, welfare and ecosystems that result from adverse developmental impacts on the natural environment. When the risk analysis is built into a framework that allows one to identify and characterise potential adverse effects of exposure to environmental hazards then the term risk assessment is used. Because so much has been done, especially in the United States, on risks to human health from hazardous chemicals, the concepts from this area have driven much of the thinking about environmental risk assessment.

American English and Australian English reverse the meanings of the words risk assessment and risk analysis. In the United States, risk assessment refers to the component of the overall process that is devoted to the calculations, whereas risk analysis is the overall process which includes risk assessment, risk management, risk perception and risk communication. In Australia, risk analysis is widely used to describe the component that is devoted to calculations, whereas risk assessment is understood to be the overall process.

The environmental impact assessment (EIA) process as undertaken in Australia is itself a form of environmental risk assessment, albeit in general, a qualitative rather than a quantitative risk assessment. An Australian EIA starts with a scoping study that determines the issues and concerns that will need to be addressed by consultation and further studies. The environmental impact statement that is produced should address the consequences arising from the identified issues and concerns. This type of scoping is also an essential part of the risk analysis process. A hazard analysis would then quantify these consequences. The essential extra step involved in converting a hazard analysis to a risk analysis is the introduction of the probabilistic element by finding an answer to the question: what is the likelihood of this hazard causing an effect? The answer to such a question involves some form of uncertainty analysis.

Figure 1 summarises the above generic framework. The left hand side lists the steps involved in undertaking the analysis or assessment shown on the right hand side. Risk assessment requires some determination of the acceptability, or otherwise, of the

numbers produced by the risk analysis. Finally, in practice, one wishes to introduce actions to control risks and to communicate these actions as part of risk management

Risk analysis and risk assessment involve judgements of probability. There are at least three ways in which this is done:

- judgements of *a priori* probability e.g. the chance of throwing double-six with a pair of true dice is one in 36;
- estimates of actual frequency e.g. there is a slightly better than even chance that any given unborn infant will be a boy;
- judgements of credibility e.g. there is now very little chance that France will cancel its atomic tests.

The first two of these methods of determining probability produce a value, when applied to hazards, that is called the actual risk or the objective risk. Risk estimates determined from judgements of credibility are known as the perceived risk, or the subjective risk. In an area as complex as the environment, there is, nowadays, a view that it is impossible to provide a truly objective measure of risk because, for example, there is subjective judgement involved in choosing the data set of historical statistics to be used to determine the objective risk.

1.2 Perceived risk versus actual risk

There is little doubt that the opinions of the public should underlie the evaluation of risk. There is no agreement on how to ascertain the opinions of the public in such a way that they can be reliably used as the basis for risk evaluation. Layfield (1987) states that:

"As in other complex aspects of public policy where there are benefits and detriments to different groups, Parliament is best placed to represent the public's attitude to risk."

People do not perceive risk solely as the expected number of deaths or injuries per unit time. People also rank risks based on how well the process is understood, how equitably the danger is distributed, how well individuals can control their exposure and whether risk is voluntarily assumed. These items can be combined into three major factors. The first is an event's degree of dreadfulness, as determined by features such as the scale of its effects and the degree to which it affects innocent bystanders; the second is a measure of how well the risk is understood; and the third is the number of people exposed. (Morgan, 1993; Slovic, 1994).

The Aboriginal attitude towards uranium mining in the Northern Territory illustrates this. The risk, as perceived by the Aboriginal community, is so great as to preclude risk management options based on technically determined actual risks. McLaughlin(1991) asks: "...Will the assurances of regulators today become regrettable errors in 20 years time?" The water management issue is one that best illustrates the wide discrepancy between the actual risk, as assessed using the tools of ecological risk assessment as they presently stand, and the perceived risk. Extreme rainfalls during the first two months of 1995 meant that the Federal authorities gave approval for the release into Magela Creek of water from the restricted release zone. On 9 March 1995 the Northern Land Council sought an injunction against ERA (who control the Ranger Uranium Mine) to prevent release. ERA offered to hold the release for a week. During that week the heavy rains ceased and the flow rate in Magela Creek dropped below a level sufficient to ensure adequate dilution. Thus no release took place.

2. The benefits in applying environmental risk assessment

Risk analysis comprises a formal set of tools that enables one to deal with uncertainty. Given that societies have long made decisions with less than complete attention to the associated uncertainties, one needs to consider explicitly the reasons for using it, and the benefits to be gained by its use.

An important point to note is that there are two separate uses for environmental risk assessment: strategic risk assessment; and tactical risk assessment. The two will be considered separately.

2.1 Strategic Risk Assessment

Strategic risk assessment refers to the use of risk assessment methods to determine corporate activities such as setting environmental priorities, allocating resources or making informed decisions.

Forecasting

A central purpose of policy analysis and policy research is to help identify the important factors and the sources of disagreement in a problem, and to help anticipate the unexpected through, for example, the development of worst-case scenarios. An explicit treatment of risk and uncertainty forces careful thought, helps identify important and unimportant factors, and assists in contingency planning.

Setting priorities

The use of risk assessment methods to set environmental priorities is encapsulated by the slogan that seeks to undertake actions on worst things first. Examples of such use comprise the setting of topics for company environmental performances reviews — especially when these are of widespread public interest as in the case of uranium mining.

Informed decision-making

The tools of decision analysis and risk assessment require systematic treatment of the possibilities and, if possible, an assignment of probabilities to each of the possibilities. The discipline required to do this informs decision-making. The tools, themselves, will not provide a unique basis from which the answer flows because the evaluation of consequences is filtered through the risk-bias of the decision maker. The debate concerning the Tailings Dam at the Ranger Uranium Mine illustrates this.

Reconciling viewpoints

It is hard to make decisions when experts differ in their judgement. If one insists that the experts divulge the uncertainties of their judgement, then it is easier to determine how much they think they know and whether they really disagree.

Cumulative impact assessment

The present Commonwealth environmental impact assessment process is constrained to deal only with the proposal under consideration. Regulatory authorities who wish to undertake planning studies on the impact of a number of similar activities would need to use risk analysis to do so.

2.2 Tactical risk assessment

Quantitative risk assessment is taken by many toxicologists as being synonymous with assessments of the adverse effects of chemicals. Tactical risk assessment includes this use of the term as well as the use of risk assessment methods to determine the risk to people from planned or existing development. This may arise, for example, from an industrial accident.

Objectivity

The use of quantitative risk assessment to determine environmental standards provides an objective method of setting such standards. To ensure that there is widespread community acceptance and awareness of the process it is vital that appropriate consultation should take place. When dealing with the technical details the consultation needs to be with the technical experts. When translating the technical details to regulatory standards then the consultation needs to be with the wider community.

Transparency of process

Choosing, and implementing, a risk assessment framework provides a transparent process for decision making. This applies both to tactical risk assessment when the process is used to determine regulations, and to strategic risk assessment.

Documentation

Problems are rarely solved permanently. If one wishes to use, or adapt, policy analyses that have been done in the past to help with present problems, then the task is made easier when the uncertainties of the past work have been carefully described. One can then have confidence that the earlier work is being used in an appropriate way.

Reduce Costs

The institution of standard methods of risk analysis provides guidance for environmental practitioners. By training a corps of people able to use such standard methods, analysis costs can be reduced because there is no need to devise individual and unique methods or models for each investigation. This aspect of risk analysis has, to date, made computer modelling particularly attractive in fields such as air quality assessment.

3. International Best Practice in Environmental Risk Assessment

Government

Quantitative risk assessment has been incorporated into the procedures and workings of many environmental agencies around the world. This use of risk assessment in the analysis of chemicals is practised world-wide though the techniques themselves differ. The European Communities favour laboratory tests, the Canadians favour field tests, whereas the United States favours computer modelling. Nevertheless, all their practitioners would agree that, depending on the circumstances, a judicious mix of these techniques may be needed.

There is a growing tendency to use comparative risk assessment as a means of setting environmental priorities. Comparative risk assessment uses the methods of risk analysis, but applies them to problems in which the actual probabilities and consequences cannot be determined from actual historic data. Instead, the probabilities and consequences need to be determined on the basis of community polling in which the various risks are compared.

Industry

Risk assessment is an integral part of quality management systems. It is needed to ensure that objectives are appropriately identified and that activities and resources applied to the achievement of the specified objectives are appropriate. Risk analysis is also useful in addressing the cost-benefit considerations of setting and achieving objectives in light of residual risk tolerances.

Risk analysis has not been explicitly included in the Australian and International standards for environmental management systems. However, risk assessment is seen as a useful component of such a system wherein it can be used to set priorities, to identify environmental problem areas and to implement procedures for risk management and reduction.

Environmental Protection

International best practice in the use of risk assessment for environmental protection manifests itself as ecological risk assessment. This generalises the concept of human exposure to an effect and deals with the response of an ecosystem when exposed to a stressor. Its use in the United States requires a combination of field tests and computer modelling.

Setting environmental standards

Risk management involves evaluating alternative policy options and selecting among them. The United States risk assessment framework separates risk management from risk analysis. Once risk assessment moves out of the toxicological area, it is difficult to maintain such a neat distinction. Cox et al. (1994) point out that:

"The separation of science (risk analysis) and economic and social welfare policy (risk management) on the basis that science deals with facts while economics deals with values is unrealistic and illusory. A clean separation is not possible. The recognition and acknowledgment that facts and values are often inseparable gives a human perspective to the technical nature of risk assessment."

We agree.

Standards comprise one of the major frameworks used to regulate, and hopefully to avoid, risk. They are a centralised process of setting permissible levels of an environmental hazard with the incentive for compliance being liability or a fine. Their advantage is that technological decisions are used to construct a uniform threshold of acceptable risk. The major drawback is that usually no attention is paid to the costs of implementation.

Other possible means of regulating risk are:

- (i) taxes and charges;
- (ii) using cost effectiveness studies to find the least costly method of achieving a pre-determined risk reduction target — the target may be set on some other basis, usually through the political process;
- (iii) cost-benefit analysis; or
- (iv) information programs through hazard warnings, labelling and risk communication.

4. Australian (Commonwealth) environmental practice

The Environment Protection Agency (EPA) is part of the Federal Department of the Environment, Sport and Territories. Its objective is to protect and enhance the environment of Australia through national leadership and cooperation.

The EPA:

- provides timely and reliable advice to Government and other decision makers about the environmental impact of proposals;
- works with others to reduce the generation of waste and to ameliorate the impacts of wastes and contaminants;
- works with others to set clear rules for protection against pollution and unacceptable environmental impacts;
- works with others to encourage better protection of the environment;
- provides independent and informed advice on the environmental acceptability of the management of specific developments nominated by Government (for example, uranium mining in the Alligator Rivers Region); and
- conducts environmental research and provides environmental advice to further the management capability for sensitive areas nominated by Government (for example, the impacts of uranium mining in the Alligator Rivers Region, the wetlands and estuaries of the Alligator Rivers Region).

The EPA is currently responsible for the assessment of the environmental effects of industrial, agricultural and veterinary chemicals, and has provided a coordinating mechanism for State authorities in relation to contaminated sites, and in relation to the siting of hazardous facilities. Overseas approaches to these issues focus on computer-based models developed in recent years. For example, the Uniform System for the Evaluation of Substances (USES 1.0) was launched in 1994 in support of the

Netherlands National Environmental Policy Plan. It is a decision support instrument for use by relevant authorities which enables them to make rapid and efficient assessments of the risks posed by substances, including new and existing substances, agricultural pesticides and biocides.

Government agencies responsible for protecting the environment face difficult decisions due to two problems that must be resolved:

- identification and quantification of a particular environmental problem;
- determination of acceptable levels of risk for society.

In making regulatory decisions, these agencies have turned to, or are considering using, risk assessment to identify substances to be regulated, to set budget and resource priorities and to select final control levels. Simulation models that can integrate both the chemical-response profile and exposure are useful in obtaining probabilistic estimates of risk.

The Environment Protection Agency (EPA) conducts a simplified form of risk assessment as part of its assessment of the environmental effects of industrial chemicals, as well as agricultural and veterinary chemicals. Despite the overseas use of risk assessment in dealing with contaminated sites, there has been little such activity by Australian regulatory authorities.

The Office of the Supervising Scientist assesses the adequacy of environmental protection relating to uranium mining in the Alligator Rivers Region and by advising on best practice in environmental protection. There has been considerable ecological, chemical and hydrological research conducted at the Environmental Research Institute of the Supervising Scientist that could form the basis for ecological risk assessment of mining activities.

Another area of present Australian practice which could benefit from the use of risk analysis is in the assessment of the impact of proposals. Many proposals incorporate risk assessments and there is no in-house capability for the EPA to determine the soundness of such analyses. Neither is there an ability to conduct cumulative impact assessment, should there be a requirement for such.

In addition to the requirement for risk assessment within the operational activities of the EPA there is scope for its use as a tool within management decision making. It has previously been mentioned that risk assessment — and risk management — is considered to be an integral part of quality management systems.

5. An Australian environmental risk assessment model

Because risk assessment is used in a large variety of different situations, a generic environmental risk assessment framework — such as that of Figure 1 — provides a conceptual picture, but cannot provide the detailed guidance for the actual steps that need to be implemented to carry out a risk assessment task. The case studies given in the report provide some guidance along these lines and indicate situations in which risk assessment is useful.

The Management Advisory Board of the Australian Public Service (MAB, 1995) identifies a five step generic process for managing risk which, they claim, can be applied at any stage in the life of a policy, program, project, activity or asset. It can also be applied to all levels of an organisation — strategic, tactical and operational. Their five steps — analogous to the generic framework of Figure 1 are in Table 1.

The context establishes the form of hazard analysis and the form of uncertainty analysis that is required. The various chapters in the attached report provide examples of the use of risk assessment to set priorities, to examine the impacts of uranium mining, and to examine chemicals. Table 2 shows how these specific examples fit into the generic framework.

Table 1 Comparison of the generic risk management process and the generic environmental risk assessment framework

	MAB PROCESS	GENERIC FRAMEWORK
Step 1	Establish the context	(Environmental)
Step 2	Identify the risks	Concerns, Consequences
Step 3	Analyse the risks	Calculations/Certainty and Uncertainty
Step 4	Assess and prioritise risks	Compare with criteria
Step 5	Treat the risks	Control, communication

Table 2 Examples of the application of the generic framework

Generic Framework	Risk Assessment Type		
	Comparative	Ecological	Chemical
Concerns	Consultation to identify issues	Stressors to ecosystems	Exposure to chemicals
Consequences	Resources at risk	Ecological Effects	Effects to humans & biota
Calculations	Quantify community concerns	Quantify hazards	Evaluate expected concentrations
Certainty and Uncertainty	Quantify likelihood of manifestation of items of concern	Pathway analysis Monte-carlo modelling	Worst-case analysis
Compare with Criteria	Prioritise	Ecosystem integrity	Q-method
Control	Act on high priority items	Restrict hazardous activities	Restrictions on use or labelling
Communication	Feedback to participants	Document publish and advise	Notify

In practice, many of the variations amongst different forms of risk assessment, such as comparative risk assessment and ecological risk assessment, arise from the way in which the analysis of certainties and uncertainties is carried out. For example, probabilistic modelling based on a Monte-carlo analysis involves four steps:

1. Develop flow charts of the system, likely emissions, pathways and fate of materials.
2. Quantify the hazards associated with each step of the process.
3. Determine probability distributions for key steps in the process and run the Monte-carlo simulations to determine the expected probabilities.
4. Rank the probabilities on the basis of some criterion.

Such an approach highlights the value of, and the need for, computer modelling. A full probabilistic assessment based on Monte-carlo modelling provides comprehensive statistical information on likely outcomes but can only be implemented using computer models.

Application of risk assessment requires capabilities in:

- systems analysis for scenario development;
- technical expertise to quantify hazards;
- statistical and computer modelling skills; and
- expertise to quantify the costs or benefits.

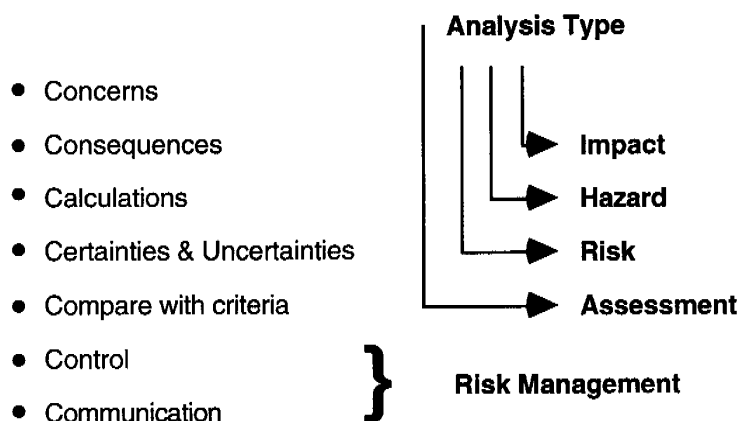
This means that any risk assessment unit needs to consist of at least four people — one in each of the above areas. In practice, more than one person would be needed to handle all the areas of technical expertise that are of relevance to the EPA which embrace chemicals, contaminated sites and issues related to mining.

Any risk assessment unit would be reliant on information technology (IT) support. The need to maintain specialised hardware and software would involve an extra person.

The case study dealing with atrazine indicates the need for a systematic examination of software to be used to assess the environmental effects of chemicals. If a suitable model is then chosen for Australian applications, it will focus data collection on the requirements of the model. At the moment, the lack of suitable databases is being used to argue against running particular models — yet there is a reluctance to collect such databases in case the wrong variables are measured. This need is one of high priority.

The issue of software is then related to the choice of computing platform. Though the IT strategy of the EPA calls for the use of Macintosh systems, most (if not all) of the software developed by the US EPA has been developed for IBM systems. An issue that needs to be determined is, then, whether a risk assessment unit should have access to both platforms — or whether there should be adherence to a single platform, with a program of software translation.

Figure 1 Risk Assessment Framework



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