Chapter 5

Worst Things First

Setting Priorities Using Risk Analysis

Introduction

Risk assessment, or comparative risk assessment to be more precise, is one of a number of tools that can be applied to the process of setting priorities. Comparative risk assessment is the act of evaluating two or more risks simultaneously and juxtaposing the results to examine whether the relative effort devoted to each risk should be changed. Often, in fact, there is a hope that risk assessment can solve complex problems with which the community has long grappled. The hope may be there, but agreement is sometimes lacking, as shown by the existence of an on-going debate in the United States over risk based national environmental priorities (Finkel & Golding, 1994).

Whether risk assessment can solve such problems depends on the nature of the problem and how inclusive one wishes the term risk assessment to be. For example, in the case of uranium mining the two reports of the Ranger Uranium Environmental Inquiry (Fox et al., 1976, 1977) comprise an extensive assessment of uranium mining, with recommendations for overall risk management and risk minimisation. The risk in this case is the risk of environmental degradation and the risk of adverse impact on Aboriginal society. What is missing from the Ranger Uranium Environmental Inquiry is a **quantitative** risk assessment that attempts to place such issues within a statistical framework.

Certain arguments refuse to die because the Ranger Uranium Environmental Inquiry did not couch its recommendations in appropriately quantified risk assessment terms. Page 150 of the second report states:

> *"The Commission recommends that the project be permitted to commence only if there is a firm, legally binding undertaking by Ranger to replace the tailings in the mine pits. We recommend elsewhere the provision of a security or surety to provide finance for this operation even in the event of the failure of the Ranger company or of it ceasing to carry on for any reason. Any stockpiles of low grade ore remaining after milling ceased should be placed with the tailings in one or other of the pits.*
>
> *Many of the long term environmental effects of the project are unpredictable... For this reason we recommend that the supervising authority should not have the ability to relax the requirement that the tailings and unused ore be returned to the pits."*

Despite such unequivocal assertions, the final legislated environmental requirement (ER) for tailings disposal from the Ranger lease was ER29 which requires all tailings to be returned to the worked out pits at the cessation of operations unless the Supervising Scientist is satisfied that, by dealing with the tailings in another manner, the environment is no less well protected.

Barrow et al. (1994) state:

> *"ER29 (Environmental Requirement 29) poses some special problems of interpretation... if the lease is extended, and mining of North Ranger and Ranger 3 occurs, then the comparison implied in ER29 is between moving the tailings from the current tailings dam to pit number 3, versus leaving them in the dam. In order for the tailings to remain in the dam the Supervising Scientist must be satisfied that the environment is no less well protected. However, the kind of risks posed by these two options differ. The pit option might contribute more contaminants to the environment on an annual basis and be more at risk from infrequent events such as a 1:10 flood, but be much less at risk from the very rare event such as a 1:100 cyclone. In contrast the tailings dam might be much more at risk from the 1:100 events and the release very much greater. We suggest that*

there is a need to consider the ground rules in terms of risk/damage for making the comparisons involved in ER29."

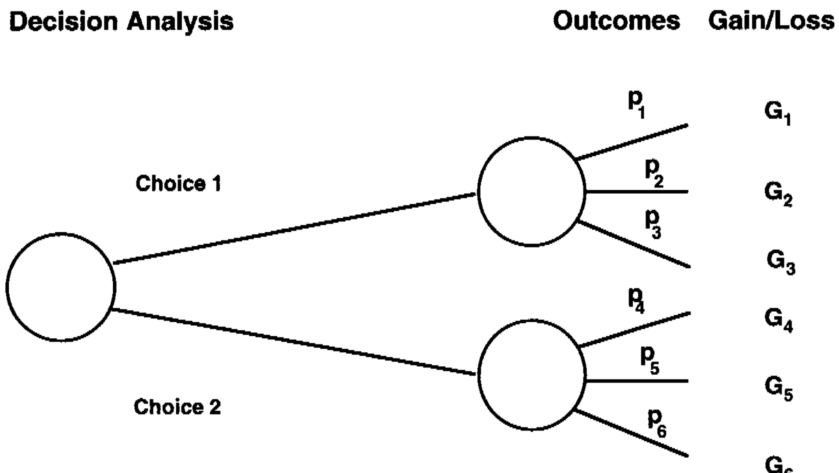
Decision Analysis

Decision analysis consists of a set of mathematical and organisational tools that help a decision maker think systematically about complex problems and improve the quality of the resulting decisions (Clemen, 1991). The essentials of decision analysis consist of the construction of a decision tree, assigning probabilities to the nodes of the tree and determining the outcomes on the basis of the probabilities. Decisions are then made on the basis of the outcomes.

Textbooks on decision analysis deal with decision tree outcomes expressed in monetary terms and deal with the concept of risk in terms of risk profiles. These are graphs which show the probabilities associated with possible outcomes. In statistical terms, one would describe the risk profile as the probability distribution function for the expected outcomes. Thus, in decision theory the concept of risk does not refer just to a single measure of uncertainty, such as standard deviation. Instead, it refers to the whole probability distribution function associated with the potential outcomes.

Decision analysis defines a risk-benefit outcome in terms of the expected monetary value. For example, if the pay-offs in a game when a coin is tossed are $30 for a win and $1 for a loss, then the expected monetary value (EMV) is $14.50. But the extension of decision analysis to deal with risk tackles the issue that people make decisions on criteria other than the EMV. For example, if the amounts in the previous case are altered so as to pay $2000 for a win, but to demand $1900 for a loss then few individuals would choose this second game despite it having an EMV of $50. Fig. 5.1 shows a general decision tree. For the two choices given above, we have

Figure 5.1 Making a Decision



$$\text{EMV Choice 1} = \frac{P_1 G_1 + P_2 G_2 + P_3 G_3}{P_1 + P_2 + P_3}$$

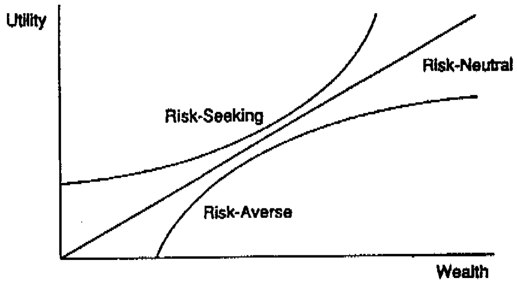
$$\text{EMV Choice 2} = \frac{P_4 G_4 + P_5 G_5 + P_6 G_6}{P_4 + P_5 + P_6}$$

$p_1 = p_2 = p_4 = p_5 = 0.5 \quad p_3 = p_6 = 0$

$G_1 = \$30 \quad G_2 = -\$1 \quad G_4 = \$2000 \quad G_5 = -\$1900 \quad G_3 = G_6 = 0$

The ultimate decision, when faced with a choice such as that of Fig. 5.1, depends on the risk attitude of the individual making the decision and this, in turn, depends on how the monetary amounts are transformed into personal utility. Thus, when risk analysis is used in decision analysis, there needs to be extensive investigation of the utility function that translates dollars to utility. Three shapes of utility functions are normally considered (Fig. 5.2). Concave utility functions indicate risk aversion (e.g. buying insurance), convex utility functions indicate risk seeking (e.g. buying lottery tickets), whereas a straight line indicates a risk neutral individual. For a risk neutral person, maximising EMV is the same as maximising expected utility. Such a person is considered to be one who does not care about risk and ignores the risk aspects of the alternatives that are faced.

Figure 5.2 Three Different Shapes for Utility Functions

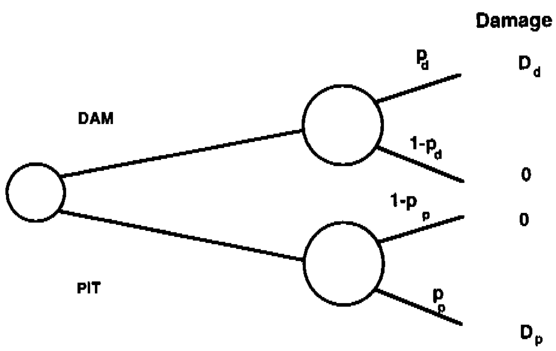


These issues are very relevant when one considers the risk assessment approach to environmental issues. Environmental impact statements that incorporate risk assessments assume that society as a whole is risk neutral, and that decisions can be made solely on the basis of the hazards (which are the environmental equivalents of the monetary outcomes considered in decision theory) and the probabilities. This has led to the situation, much lamented by technical experts (eg National Research Council, 1989, p.52), in which certain activities, such as nuclear power, evoke much more serious public opposition than others, such as motorcycle riding, that cause many more fatalities. As we have previously discussed in Chapter 1, and depicted in Fig. 1.2, the familiarity and controllability of the risk plays an important role in the way it is perceived.

Dam versus pit — a simple decision tree and utility curves

The option between dam and pit, as presented above, can readily be presented in the form of a decision tree. Decision trees are used as a management tool to decide between competing options, as shown in Fig. 5.1. A probability is assigned to each of the outcomes and the likely financial rewards from each outcome is also estimated. The expected mean value (EMV) of each choice is then the sum of the products and probabilities corresponding to each of the outcomes associated with that choice.

Figure 5.3 DAM vs PIT



The decision tree for the dam versus pit option is shown in Fig. 5.3. The probability of environmental damage as a result of a cyclone impinging on the dam is set at P_d whereas the probability of environmental damage as a result of a flood affecting the pit is set at P_p . In doing the quantitative analysis it is important to note that Bayesian statistics need to be used. The probability of release of material as a result of a 1/100 cyclone is not 1/100 but is

$$P_d = P\,(R|c) \times 1/100$$

where P (R | c) is the probability of release of material in the presence of a 1/100 cyclone. P(c) = 1/100 is the chosen probability for the cyclone.

The damage resulting from the two events is unknown. Thus it has been shown in Fig. 5.3 as being D_d for dam failure and D_p for pit integrity failure. The expected mean value (EMV) of the damage arising from the dam is then P_dD_d and the EMV of the pit is P_pD_p . A choice based solely on an EMV criterion would then advocate the pit option if its EMV is lower than the EMV of the dam. That is, choose the pit if $P_dD_d > P_pD_p$.

The probabilities that are assigned depend on the nature of the engineered constructions that are in place. At present, the tailings dam at Ranger is designed to contain water and prevent the tailings dam from overflowing up to a 1 in 10 000 year storm (McQuade, pers. comm.) implying that P(R | c) is about 1/100. The probability of release of material from the pit to groundwater at some (unknown) time in the future is virtually certain. A first estimate, then, would be to set P(R | f) = 1. Thus, as an extremely simplified example, if we use the values advocated by Barrow et al. (1994) and compare the results of a 1/10 flood and 1/100 cyclone, the probabilities are $P_d = 1/10\,000$ and $P_p = 0.1$ so that $P_p/P_d = 1000$. If $D_d/D_p > 1000$ then the pit is to be preferred, whereas if $D_d/D_p < 1000$ then the dam is to be preferred.

The analysis of probabilities is too simplistic because it ignores likely engineering considerations, and the more likely pathways of releases to the environment. Waggitt (1994) reviews typical design considerations and their relative advantages and disadvantages. In a detailed study of the above ground tailings containment for mine rehabilitation (Waggitt & Riley, 1994) it is pointed out that the risk of release of tailings is a function of time and that it could fail as the result of the cumulative effects of a number of medium sized events over a long period of time, with a figure of 1 000 years being given as typical for the structural life of the dam.

We now have the situation of a cumulative probability distribution function with two known points. The probability of failure is zero at t= 0 (the dam is still standing) and the probability is one at t=1000. The question of interest is: what is the probability of failure within the next year — at t=1. The answer to this question depends on the shape of the curve that is drawn connecting the two points. The simplest answer is to draw a straight line which implies that the probability of release in any particular year is $P_d = 1/1000$.

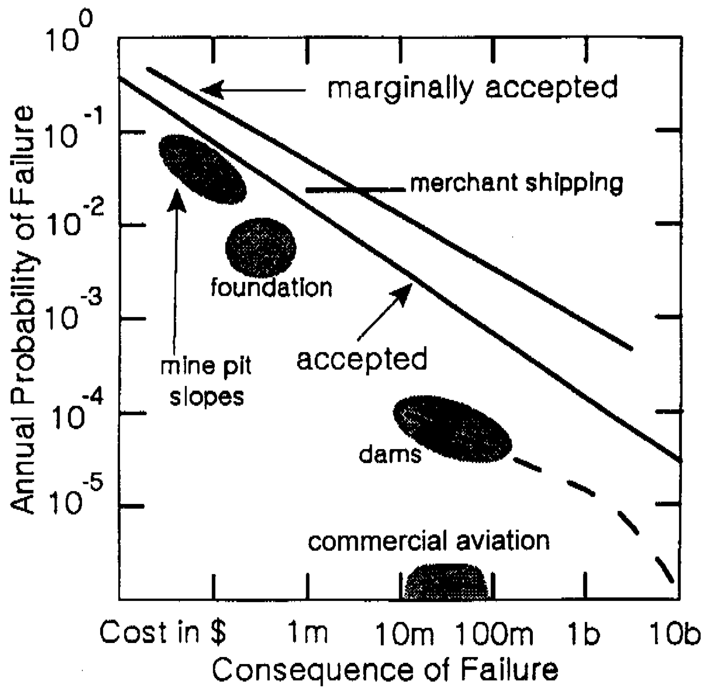
The choice of curve is arbitrary, though professional practice determines the shape in many areas of science and engineering. Much of the technical argument related to risk analysis arises because of this arbitrariness in curve fitting. Paustenbach (1995: Fig. 1) discusses an analogous case in toxicology where scientists must rely on a model or theory to provide the appropriate curves to estimate human responses at doses well below the lowest animal dose tested. In an effort to derive risk estimates that are unlikely to underestimate the risk, the models most frequently used by regulatory agencies assume non-zero values everywhere except the origin. A similar justification could be used to justify the linearisation of the probability.

It may also be argued that the environmental hazard from retention of mine tailings in the pit is not the leaching of contaminants into groundwater, which will occur during every severe storm and flood. The environmental hazard occurs when the contaminated groundwater reaches the nearest flowing water body. The time for this is not known, but some 'back-of-the-envelope' calculations of Dillon (1991) indicate that groundwater movement from Pit 3 could be as high as 5 m per year. Magela

Creek is only about 100m from the northern edge of No. 3 ore body, so that there remains the possibility that there will be environmental release of pit-disposed material within 20 years. Thus, we take the probability of release in any particular year as $P_p = 1/20$.

There remain many problems with the above simple example of a decision tree. Firstly, the EMV criterion given above assumes episodic event-based damage and refers only to the EMV up to the expected time of the first event, or expressed alternatively, it analyses risk in the first year after decommissioning (assuming a linear increase in the cumulative probability of failure). This is accepted decision analysis procedure. Alternative viewpoints can arise because, over a 1000 year period, there is an expectation of a release from the tailings dam, but over this period the probabilities correspond to the occurrence of 50 releases from the pit. If the damage per pit release stays the same then the EMV criterion for choosing the pit becomes: choose the pit if $P_dD_d > 50\ P_pD_p$. Further difficulties arise if one considers that once the contaminated groundwater plume from the pit reaches the receiving waters, then there will be continuous flow into the water system, but release from the dam is likely to be episodic.

Figure 5.4 Risks for Selected Engineering Projects



The values of D_d and D_p are not known and are difficult, if not impossible, to calculate. Further, the values of D_d and D_p are unlikely to be constant values. Whitman (1983) points out that the consequences of failure — expressed either as lives lost or as a cost in dollar terms — generally increase as the probability decreases (Fig. 5.4). This ties in with the accepted view that a tailings dam release would lead to widespread damage (D_d is very large) whereas the damage from release from the pit is much lower. An alternative viewpoint, espoused by mining company representatives, is that at very low probabilities D_d approaches zero, because it would require a catastrophic event to breach the tailings dam. The overall devastation during such an exceptional event (eg. the combination of an earthquake and an intense tropical cyclone) would be so large that the contribution of the tailings dam would be negligible. Support for this viewpoint would also be found from the standard economic concept of discounting future damage to present day dollars. A very large damage occurring in 1000 years time when discounted is generally very much less than a moderate damage occurring in 20 years time.

Figure 5.5 (a, b, c) EMV - PIT/DAM

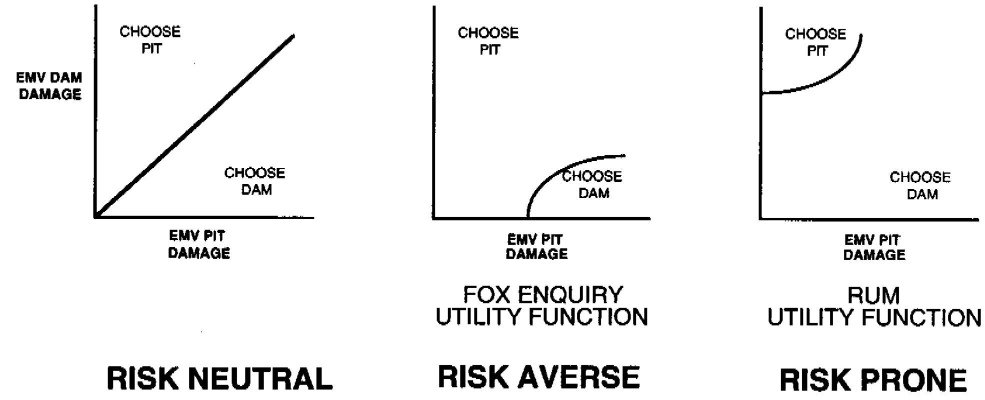


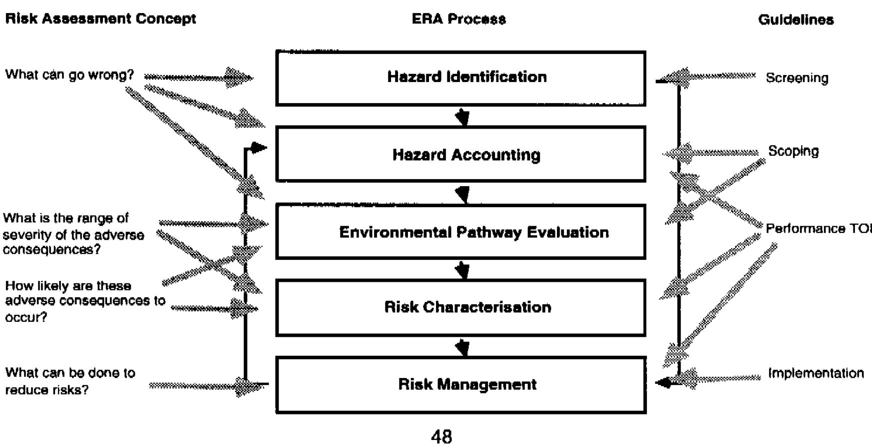
Figure 5.5 illustrates three utility functions. Fig. 5.5a corresponds to the utility function discussed above. The choice of pit or the choice of dam is determined by the lower EMV. The Ranger Uranium Environmental Inquiry used a utility function that could be approximated by the one shown in Fig. 5.5b. A pit was to be preferred, regardless of the possibility of pit failure. The figure, however, allows for the possibility that if the cost of pit failure is shown to be very high, then the dam would be chosen. The mining company, however, appears to have a utility function as shown in Fig. 5.5c. The preferred choice is the dam, unless — presumably — it can be shown that the cost of dam failure is so high that it is an indefensible choice.

It has long been known that utility curves indicate risk attitudes of the individual (Clemen, 1991, Ch. 13). A straight line utility curve, such as Fig. 5.5a is that of a risk neutral individual. The convex boundary of Fig.5.5b is interpreted to be that of a risk averse individual, whereas the concave boundary of Fig. 5.5c is that of a risk seeking individual. The role of investigation, study, consultation and debate is to transform the individual utility functions to risk free utility functions.

Prioritising issues

Figure 5.6 depicts the concept, process and guidelines for environmental risk assessment (ERA) as promulgated by the Asian Development Bank (Office of Environment, 1990). The first step of a risk assessment is to identify and list the hazards associated with the operations performed. This is termed screening in the ADB guidelines. As a case study in the use of comparative risk assessment, the next section considers its use and applicability for setting the nature of the topics to be discussed in future six-monthly environmental performance reviews of the Ranger Uranium mine.

Figure 5.6 Relationship of basic concepts to the ERA process and the Guidelines



The Asian Development Bank concept of using a matrix to determine risk is illustrated in Figure 3.5. The concept is one of evaluating risk on the basis of two variables — likelihood of occurrence, and severity of consequences. One can also set priorities using two variables. Australia's research organisation, CSIRO, sets its research priorities (and hence its funding allocations) on the basis of an attractiveness-feasibility matrix that is intended to determine the return to the nation of particular research areas (CSIRO, 1994). The national research priorities determined in 1994 for the next triennium placed the area of Mineral Resources in the far right of the matrix, being highest in attractiveness to the nation and second highest in feasibility.

Attractiveness considers both the potential economic, social and environmental benefits from successful research and Australia's ability to capture these benefits by converting new knowledge of technical progress into realised gains.

Feasibility considers both the potential for progress in the relevant areas of science and technology and Australia's capacity to undertake the necessary research in a timely manner.

The lowest area on the attractiveness-feasibility scale was social development and community service. This reflects the fact that this is not an area of core competence for CSIRO but needs to be undertaken as an ancillary to research conducted for other purposes.

Case Study: Environmental Performance Reviews (EPR)

Under new supervisory arrangements documented in the 1993-94 annual report of the Supervising Scientist (Supervising Scientist, 1994) routine site inspections of the Ranger Uranium mining operations were replaced with twice-yearly reviews of the environmental performance of each uranium mining operation. This arrangement was implemented to avoid unnecessary duplication by the Office of the Supervising Scientist (OSS) of some of the regulatory and monitoring responsibilities of the Northern Territory regulators in respect of uranium mining. The reviews are designed to address both the environmental impacts of the mines and the environmental management, research and planning activities of the mining companies with a view to determining the likely future environmental performance of the mines. Particular attention is given to identifying any mining practices, procedures and measures that threaten the Alligator Rivers Region environment.

The reviews are undertaken jointly by a review team comprising officers of the OSS and the Northern Territory Department of Mines and Energy. The review process involves construction of an extensive questionnaire on environmental performance, meetings with companies to gather responses to the questionnaire, examination of documentary evidence to verify the responses given, a site inspection and an evaluation of the adequacy of the responses given to each question. To date, two environmental performance reviews have been conducted. The first was from 11-14 July 1994 and the second was from 2-8 December 1994. The first review, EPR1, emphasised the outcomes of environmental management practice at the mine sites and included more detailed questions that examined operational aspects relevant to achieving the environmental outcomes. The second review, EPR2 , concentrated on the mine's water management system.

The areas covered in EPR1 and EPR2, and the number of questions in each area, are:

EPR1

1. Environmental Management	
overview	6
environmental preparedness	3
legislation and general	7
2. Environmental and public health monitoring and reporting	
overall impact	9
monitoring regimes	8
general monitoring	17
3. Water management	
overview	6
water storage and disposal	7
4. Mine and mill operation	
mine and stockpiles	5
metallurgical plant	5
tailings retention system	7
support services	5
5. Environmental research	2

EPR2

1. General	
matters arising from EPR1	7
impacts during review period	13
Best Practicable Technology	5
2. Water management system overview	
management plans	11
implementation of water management	17
3. Water storage system	
RP1	3
RP2	4
RP3	2
RP4	7
tailings system	6
4. Water disposal system	
land application area	10
Georgetown Creek	1
5. Groundwater	
groundwater management	5

Discussion

Within the context of a risk assessment framework, the EPR process is a risk-screening process. Only those issues that fail to meet an acceptable criterion need to go through the further stages of the process shown in Fig. 5.6 — including management. Yet, in determining the questions, their topics, their nature and their number, some form of pre-screening must have been established. For example, the inclusion of one question on Georgetown Creek in EPR2 is an indicator that there was a perception that this issue should be raised. No questions were included on other creeks.

The question on Georgetown Creek was included because water quality in Georgetown Creek catchment was given only minor coverage in the Annual Environmental Report of the mining company, although the occurrence in July of the second highest sulfate concentration (11 mg/L) recorded for Georgetown Billabong was described. The NT Supervising Authorities (1994) attribute the occurrence to dumping of waste rock in the Georgetown (Corridor) Creek catchment. The OSS considered that the 1994 sulfate concentrations did not pose an environmental threat, but the high rate of increase could possibly impact on Magela Creek in the future (Office of the Supervising Scientist, 1994). The question was there because it was perceived that a future environmental risk may flow from that source.

To try to determine perceptions of future risk, and perceived sources of future environmental risk, it was necessary to interview those concerned with these issues. A program of discussions was arranged during a visit to Darwin and Jabiru. Issues of concern raised either directly or indirectly during discussions were noted and a list compiled, as given in Appendix 1.

The Asian Development Bank (Office of the Environment, 1990) uses a matrix to categorise risk. The two axes are: frequency of occurrence; and severity of consequences and damage. Each axis has four possible values and the acceptability or unacceptability of the risk is determined graphically on the matrix in a procedure that is equivalent to the sum of the two values. The categories given in the ADB matrix are not appropriate ones to use to determine priorities for future EPRs. The reason is that the ADB matrix has to be able to evaluate a project *ab initio*. Thus, the range of consequences and damage to the ecosystem run from: a minimum of slight, quickly reversible damage to few species; to a maximum of complete, irreversible and immediate destruction of all life. The risk management procedures implemented as part of the procedures governing uranium mining ensure that such a risk is a very remote possibility. Accordingly, it seems to be more relevant to use a criterion of perceived risk as determined by community concern. This concept of comparing risk (i.e. likelihood of occurrence) to other factors such as community concern, or to the EPA budget was an independent re-discovery of ideas produced by the US EPA (1990). Ranking of the issues, on the basis of the discussions, has thus been done on the basis of the scoring given in Table 5.1

Table 5.1 Ranking for risk prioritisation of EPR topics

Score	Likelihood of occurrence	Community concern
1	Remote, but possible	negligible
2	Occasional, sometime occurs	marginal
3	Reasonably probable, several times	critical
4	Frequent, repeatable	unanimous

High priority items

The two items that scored highest were: (i) the release of mine site water; and (ii) the problems associated with decommissioning and rehabilitation. There was little doubt that the water management system was the single topic about which there was the most community concern and it was appropriate for it to be tackled soon after the EPR process was initiated. The assessment below indicates that it remains a high priority item which will need to be examined at frequent intervals.

Other high priority topics are:

- risk of possible impacts on surface waters;

- the water management system;
- coping with public concerns over uranium;
- maintenance of the Kakadu ecosystem; and
- the responsibilities of the mining company after decommissioning.

Topics that are relevant but of lower priority are:

- tailings dam — its management, risk of collapse and eventual rehabilitation;
- major industrial accident;
- societal disturbance from exploration activity;
- sacred sites;
- ecosystem preservation; and
- consultation with all key groups.

On the basis of the above list the following major topics need to be addressed in future EPR:

1 Plans for decommissioning and rehabilitation
2 Coping with public concerns
3 Plans for coping with industrial accidents
4 Ecosystem maintenance

The need for adaptive assessment

The above list of four topics provides a risk assessment framework to identify the themes for four future EPRs. It would be inappropriate to produce more than four topics, and one may argue that even four is too many, because it implies a planning horizon of two years. It is unlikely that a risk assessment based on the community concerns of January 1995 will still be valid in January 1997. One would expect new, possibly even unforseen, problems to arise and become concerns. Thus, the process of setting topics for EPRs needs to be an adaptive process that is capable of responding in case of a sudden, new development. Such an adaptive assessment regime would also be capable of dealing with the likelihood that after two years it would probably be appropriate to look again at the high profile issue of the environmental performance of the water management system.

An organisation such as the Office of the Supervising Scientist needs sufficient flexibility in the EPR process to be able to ask questions related to important issues that have arisen since the previous EPR. At the same time there is a need to avoid the appearance of entrapment by springing unexpected questions. One way of resolving this dilemma may be to have sections of every EPR that do not follow the main theme of the EPR but are regularly devoted to issues such as: (i) operational aspects of the mine's environmental performance; and (ii) significant recent issues.

This document has, to date, outlined a risk assessment approach to prioritisation. However, the quantitative risk analysis — which consisted of the assignment of values for likelihood and community concern — were allocated by a single risk analyst. Though these should approximate community concerns, as voiced during discussions in the Northern Territory, any final determination of EPR themes should be based on a list of questions, along the lines of those in the appendix, being distributed to the relevant persons (mining company, traditional owners, supervising authorities, politicians etc.) who are asked to assign the values 1 to 4 to both the likelihood and to the community concern. The final ranking would then be based on the sum of the mean scores.

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