BEST PRACTICE
ENVIRONMENTAL
MANAGEMENT
IN MINING

Environmental Risk Management

Environment Australia
Department of the Environment and Heritage

ACKNOWLEDGMENTS

Environment Australia wishes to thank the following people for their assistance in producing this booklet: the principal author Peter Dryden, of McCracken Consulting; Prof Tom Beer of CSIRO, the review team comprising Graham Terry, Ian Lambert, Stewart Needham, Denis Brooks, Michael Krockenberger, Dr David R Jones and Graeme McIlveen and the steering committee comprising representatives of the mining industry, government agencies and peak conservation organisations—the Minerals Council of Australia (MCA), the Australian Institute of Mining and Metallurgy (AusIMM), individual mining and energy companies, research institutions, the Australian Conservation Foundation (ACF) and the Australian Minerals and Energy Environment Foundation (AMEEF). Prof Beer, the review team and steering committee assisted the author without necessarily endorsing his views.

Environment Australia also wishes to thank the following sponsors providing financial support for the Best Practice Environmental Management in Mining project (detailed in the inside back cover):

Partner: Rio Tinto

Sponsors: North Limited; MIM Holdings Limited; Pasminco Limited; and Alcoa of Australia Limited

The series illustration of the Koalas by Christer Eriksson, commissioned by BHP Transport 1988. Reproduced courtesy of BHP Transport.

Cover photo: Cannington, south east of Cloncurry, Queensland. Fuel, oil supplies, chemicals and reagents are stored in signposted areas which are bunded to ensure containment in the event of a spill. Risk assessment can identify such potential problems.

Photo: BHP Minerals.

ISBN 0 642 546304 of the series 0 642 19418 1

Environment Australia incorporates the environment programs of the Federal Department of the Environment and Heritage.

SPONSORS

The Best Practice Environmental Management in Mining Program is a joint undertaking by the Australian Government and the Australian mining industry. Direct financial assistance* in producing five booklets (i.e. *Water Management, Cleaner Production in Mining, Atmospheric Emissions, Contaminated Site Cleanup* and *Environmental Risk Management*) has been provided by the following companies:

Partner: RIO TINTO

Sponsors:
- North Limited
- MIM Holdings Limited
- Alcoa of Australia Limited
- Pasminco Limited

Their support, and the leadership it demonstrates in improving the environmental knowledge and performance of industry, is gratefully acknowledged. These companies, and others, have also contributed material and research support to the series, including practical case study examples of best practice in action.

* The level of support is recognised through three categories:
Partner ($20,000); Major Sponsor ($10,000); Sponsor ($5,000).

FOREWORD

Environment protection is a significant priority for our society. A major role for government is setting environment standards and ensuring that individuals and organisations meet them. Increasingly, however, government, industry and community organisations are working as partners in protecting our environment for present and future generations.

Representatives of the minerals industry in Australia and Environment Australia, (the environment arm of the Federal Government), are working together to collect and present information on a variety of topics that illustrate and explain best practice environmental management in Australia's minerals industry. This publication is one of a series of booklets aimed at assisting all sectors of the minerals industry—minerals, coal, oil and gas—to protect the environment and to reduce the impacts of minerals production by following the principles of ecologically sustainable development.

These booklets include examples of current best practice in environmental management in mining from some of the recognised leaders in the Australian industry. They are practical, cost-effective approaches to environment protection that exceed the requirements set by regulation. Australia's better-performing minerals companies have achieved environmental protection of world standard for effectiveness and efficiency—a standard we want to encourage throughout the industry in Australia and internationally.

These best practice booklets integrate environmental issues and community concerns through all phases of mineral production from exploration through construction, operation and eventual closure. The concept of best practice is simply the best way of doing things for a given site.

The case studies included in these booklets demonstrate how best practice can be applied in diverse environments across Australia, while allowing flexibility for specific sites. Each booklet addresses key issues by presenting:

- basic principles, guidance and advice;
- case studies from leading Australian companies; and
- useful references and checklists.

Mine managers and environmental officers are encouraged to take up the challenge to continually improve their performance in achieving environment protection and resource management and to apply the principles outlined in these booklets to their mining operations.

Stewart Needham
Co-Chair, Steering Committee
Assistant Secretary
Science Group
Environment Australia

Pamela Ruppin
Co-Chair, Steering Committee
Manager
Aboriginal & Environmental Affairs
Pacific Coal Pty Ltd

EXECUTIVE SUMMARY

Environmental risk management (ERM) involves a complex range of interacting factors. If ERM is not implemented carefully and judged on the balance of all impinging factors, the flawed judgement that is made is likely to have serious implications for the environment as well as the project's viability. This is without even considering the legal ramifications to the companies involved and their directors.

Risk is an unavoidable element of our everyday lives, and is also unavoidable in industrial activities such as mining operations. In mining, through action or inaction, decisions are constantly being made which affect the likelihood of adverse outcomes from intended or unintended effects of those operations or from the effect of external forces or events.

This booklet sets out most of the key considerations in ERM and shows it is no longer good enough to approve operational plans by default ('what we have always done before') or by 'gut feeling'. These decisions, which can have major operational and financial implications as well as serious potential for environmental impact, deserve optimal risk management.

The approach must be systematic and offer considerable benefits including improved environmental protection performance; it must be case specific and cost effectively target environmental risk management measures; and demonstrate due diligence. The ERM process requires careful analysis of the facilities or operations covered, to give organisations a significantly improved understanding of the facilities or operations they manage. Properly applied ERM can improve environmental performance, optimise resource use, and transparently reflect performance effectiveness.

Mining can never have zero environmental impact and there is always a degree of uncertainty about the type and extent of adverse impacts which could arise. Risk management has a vital role to play, because the likelihood of adverse consequences cannot be entirely eliminated without making mining operations technically or economically non-viable. While ERM is well established in some industries, it is in its early days in the mining industry. Experience already shows its effectiveness in helping to protect the operation's bottom line. Financial and insurance industry requirements are also driving a requirement for more rigorous environmental risk exposure decisions.

The terminology used in the risk assessment literature varies between countries and practitioners so it is important to reread the author's definitions of 'analysis' and 'assessment'.

The key point is that the debate in the literature about the 'correct' terminology doesn't matter, but the substance does. The very core of risk methodology, the part which adds value, is the analysis—breaking down the system and its hazard and risk attributes to their constituent elements and exploring, examining and testing those elements and their linkages and interactions. Where rigorous analysis is replaced by superficial processes, which tend to reveal only the obvious, the value of the exercise is diminished. Risk management based on such work is not only likely to be misguided but also inadequate.

ERM is not simply dealing with 'actual' or 'real' risk but about ensuring that all relevant risk issues are addressed. It must address issues (perceived risks) identified by the community, as well as controversial or likely controversial issues. The hazard identification process should therefore consider all hazards of community (and workforce) concern and be careful not to set them aside without clearly demonstrating they will not pose unacceptably high levels of risk.

Risk communication needs to be seen as integral to ERM, not limited to simply informing the public of the assessed levels of risk and the intended management arrangements. The section on Risk Management and the Future points out that ERM is likely to play a bigger role in the environmental management of mining in the future than it does today. Additional performance-based regulatory requirements are likely to foster this trend.

At the same time, the continuing move in Australia and other OECD nations to make directors, managers and workers increasingly personally liable for environmental incidents should result in increasing resort to risk analysis/assessment to demonstrate due diligence as a defence should incidents or undesirable outcomes occur. The global trend for society to be increasingly litigious will also tend to reinforce the need for demonstrably rigorous ERM principles.

In addition, the current trend of introducing risk and performance based approaches into regulatory matters which overlap with ERM, including occupational health and safety matters, dangerous goods control and land use control, could also be significant.

A range of other issues could become increasingly important in coming years. These longer term perspectives and issues, such as greenhouse gas emissions, climate change, ecologically sustainable development and intergenerational equity, are all likely to become major factors in ERM. Pressure for quality risk communication might also be expected to grow. Consequently, ERM in mining will only grow in importance.

Those mine operators who head down this path sooner rather than later are therefore more likely to gain the significant benefits that can be expected to accrue from best practice environmental risk management.

CONTENTS

1. WHAT IS ENVIRONMENTAL RISK MANAGEMENT?

1.1 INTRODUCTION

This booklet addresses the principles of applying environmental risk management (ERM) to the overall management of environmental issues associated with mining operations and related activities. It also aims to provide practical advice to those responsible for planning, developing, operating and regulating mining activities on the best way to apply risk management to protect the environment and efficiently allocate resources.

The management of risk is inherent in all our daily activities. Almost every action we take, or do not take, affects our risk exposure. Choices over simple day-to-day things, such as what we eat, how we travel, what physical activity we engage in, or how much sleep we get, can directly influence the type, consequences and likelihood of adverse outcomes. This is no less true for mining operations where decisions to act or not to act are constantly being made. Many of these decisions affect the likelihood of adverse outcomes from intended or unintended effects of the mining operations or from the effect of external forces or events.

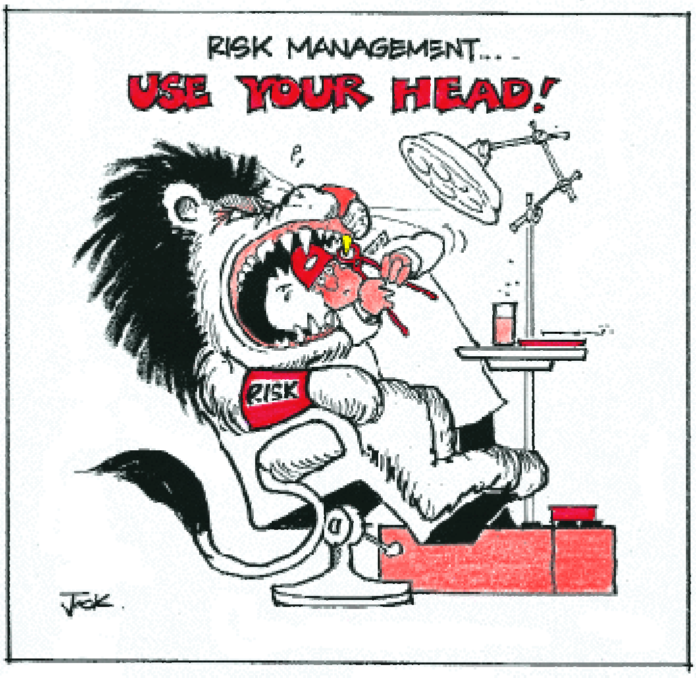
Environmental risk management encompasses:

- **s**ystematically applying policies, procedures and practices to hazard identification;
- **t**he consequences of those hazards;
- **e**stimating risk levels (quantitatively or qualitatively);
- **a**ssessing those levels of risk against relevant criteria and objectives; and
- **m**aking decisions about, and minimising, the identified risks.

In the past, these risk management decisions, which can have major operational and financial implications as well as serious potential for environmental impact, have often been made by default or based on tradition or 'gut feeling'. Not surprisingly, this does not always result in optimal risk management. The purpose of this booklet is to present the alternative approach of systematic analysis of risk exposures and the development of well-targeted and cost-effective risk management programs based on that analysis.

This systematic approach offers considerable benefits including improved environmental protection performance, case specific and cost-effective targeting of environmental risk management measures and demonstrable due diligence. The ERM process necessarily requires careful analysis of the facilities or operations covered and gives organisations a significantly improved understanding of them.

Properly applied ERM can markedly improve environmental performance and can also optimise the use of resources in mining operations and in environmental protection activities.



A structured and systematic approach to risk management enables environment protection measures to be well targeted rather than either excessive or inadequate.

As the ERM process is iterative with strong linkages between its various elements and as it is expected that this booklet will sometimes be referred to for advice on particular elements rather than being read from start to finish, there is some repetition of important points.

1.2 SCOPE

The booklets in this series aim to cover the key issues relevant to environmental management in mining. In spite of extensive cross-referencing between the booklets, there is inevitably some overlap of information. This is particularly so for ERM, as almost every aspect of environmental management has some uncertainty attached to it.

Risk consideration is relevant whenever mining facilities or operations interact with the environment and there is a potential for adverse impacts. Generally there is some possibility, however slight, of technical, operational and organisational controls and systems failing to prevent adverse consequences. In addition, when it comes to issues associated with impacts on environmental systems, and indeed aspects of mining operations themselves, there is often a significant degree of uncertainty as to the likelihood and consequences of actions and events.

The extent to which risk management is an essential part of overall environmental management is illustrated by the coverage of risk-related issues in other booklets in this series. The reference to risk is most explicit in the *Environmental Auditing, Mine Planning for Environment Protection*, and *Managing Sulphidic Mine Wastes and Acid Drainage* booklets but risk issues are also covered elsewhere in this series. As far as possible, this booklet cross references the others rather than covering the same territory.

This booklet uses a broad definition of 'environment', encompassing not only what is sometimes termed *'the natural or the biophysical environment'* but also human health and community values. The scope therefore includes issues of social and cultural impact but does not extend to socio-economic issues such as employment and expenditure effects.

Occupational health and safety issues ('the workplace environment') have been specifically excluded, except where the core matters covered in this booklet also relate to OH&S factors. Managing hazardous materials, an issue which clearly has a bearing on both OH&S and environmental safety, is covered in the *Hazardous Materials Management, Storage and Disposal* booklet but is also encompassed within the scope and methodological framework of environmental risk assessment and management covered by this booklet.

The use of the products of mining operations is also outside the scope of this booklet, so greenhouse gas and climate change impacts related to such usage are not covered. The degree of uncertainty about greenhouse gas effects and climate change means risk assessment must be applied to these. In most instances, however, it is likely that separate analysis of such issues would be more appropriate and effective.

The direct impacts on greenhouse gas emissions and climate change from mining operations, on the other hand, may fall within the scope of ERM as covered by this booklet. For example, the effects of vegetation clearing and release of gases from mining and related operations, including gas releases from energy consumption, may need to be covered in the active management of environmental risk by the mine operator.

Natural events can affect mining operations but a detailed discussion of these is beyond the scope of this booklet. However, ERM must cover natural hazards and how these can affect mining operations and, consequently, the environment. There are likely to be site-specific hazards facing particular operations and these should be part of assessments made for that site. Equally, where mining developments or operations alter the likelihood or severity of natural hazard events (e.g. increased bushfires because of additional ignition sources, or changes in flood frequency or severity because of changes in stormwater runoff), the changes must also be reflected in ERM planning.

The nature and scale of operations determine if relevant environmental effects will occur within the directly controlled site or sites or extend well beyond site boundaries. During mine operation, the scope may be limited to the principal extractive activity or may encompass processing, land transport, loading facilities and shipping. Over the entire period covered by the mining process, however, the scope extends from exploration and concept development through to the mine closure, rehabilitation—and even beyond this if, there is potential for delayed or future impact. These issues are discussed further in Section 2.3 in which scoping particular risk assessment studies is discussed.

While this booklet deals primarily with ERM, it is essential to remember that, for effective overall management of any mining operation, the management of environmental aspects must be fully integrated with the general management of the facility. This is at least as true for risk management as it is for other aspects of environmental management. If risk management is not integrated, measures taken to manage risk of one type could have the unintended and unforeseen effect of exacerbating other types of risk. One area in which risk management conflicts sometimes arise is environment and occupational health and safety. For example, solutions that remove pollutants from the immediate working environment may have the potential to harm people offsite or the biophysical environment.

Finally, the ERM process should not be seen as just technical in nature. It also needs to deal with perceived risk (in the community, workforce and industry) and be seen to do so. Risk communication is therefore an important component. For the community to be confident that the environment will not be at risk, the results of robust and transparent analysis must be reported clearly and candidly.

1.3 HISTORY AND BACKGROUND OF ERM

Just as risk management has been an inherent part of mining activities over the years, so has some implicit form of risk assessment*. What is new is the formalisation of risk assessment and management processes, the increased and increasing emphasis on environmental protection and management, and regulatory requirements being developed for ERM.

There are many precursors to the environmental risk assessment and management approach now being implemented in the mining industry. The two most important underlying influences are:

- the increasing recognition since the 1960s of the significance of environmental impacts and accompanying regulatory requirements for protection of the environment; and
- the development of risk-based approaches to control and management of environmental hazards.

Early environmental protection measures tended to be limited to pollution control and favoured, a prescriptive regulatory approach. This has evolved into sophisticated, performance-based approaches which have led to the performance of operators being scrutinised much more intensively. Giving teeth to these approaches are the increasingly heavy penalties for environmental harm or potentially harmful behaviour. This has promoted the use of environmental auditing and a greater emphasis on risk-based approaches. The pace at which these approaches have been adopted reflects the need to match environmental management to the level of potential adverse outcomes. This is because potential environmental harm has implications for both the operator organisation and its directors and officials, who are increasingly being held legally liable.

In parallel with the control of pollution and other environmental impacts of ongoing operations, rigorous environmental impact assessment (EIA) requirements have been developed for proposed new facilities. Again, risk-based approaches are proving useful in dealing with uncertainties in proposals. Inclusion of risk assessment in EIA is also increasingly a requirement of approving authorities.

Photo: Graham A Brown & Assoc

Correct bunding of fuel and other liquid storage tanks on mines and mineral processing facilities is essential to minimise environmental risk.

The development of structured and formalised risk assessment and management has essentially been driven by a recognition that the possibility of unintended adverse outcomes cannot always be eliminated. There is a need for a way to judge:

- severity and likelihood of those outcomes;
- suitability and cost-effectiveness of control measures; and
- acceptability or tolerability of the risk remaining after available control measures had been implemented.

The rigorous risk-based approach first came to the fore in the nuclear industry and, to an extent, in the space industry, where systems were complex and the need for high reliability was clear. In the 1960s and 70s rigorous quantitative methods and supporting databases were developed.

After major industrial incidents in the mid-seventies (most notably a cyclohexane explosion at Flixborough in the UK in 1974 and a dioxin release at Seveso in Italy in 1976), the nuclear industry's methodological framework was applied to the chemical and petroleum industries in Europe in the 1980s. Regulatory requirements were established for major hazard facilities, that is, facilities that handle nominated quantities of hazardous materials. In the UK, this was implemented through the CIMAH Regulations and in Europe through the Seveso directive, implemented in various ways by the EC nations.

A feature of the nuclear industry and the European chemical industry work was that the focus was not principally on safety issues on-site but on impacts in the wider 'off-site' environment. The focus of the regulations and early work was, however, on human fatality and, to a lesser extent, human injury. As part of CIMAH regulations and the Dutch implementation of the Seveso directive, the risk-based approach was further developed. This led to a decision-making framework for landuse planning control, affecting the location of facilities and the development of lands surrounding facilities, to be produced.

In Australia, in the early 1980s, the risk-based, land-use planning approach was taken up by the (then) NSW Department of Environment and Planning. The approach was extended to include injurious effects and, notably, impacts on the biophysical environment. Other States and Territories in Australia have subsequently adopted this approach for assessing new and existing developments.

More recently, the International Labour Organisation (ILO) and the National Occupational Health and Safety Commission (WorkSafe Australia) have turned their attention to type of facility that is a major hazard. *A Standard for the Control of Major Hazard Facilities* (1997), incorporating requirements for risk assessments, has been developed and is being implemented in some jurisdictions. WorkSafe has also published risk-based standards for plant and hazardous substances.

The USEPA has also played a significant role in developing environmental risk assessment and management, most notably through its work on contaminated sites in which detailed quantitative risk assessment methods were developed.

Other contributors to the total ERM picture ('SCALE factors') have included:

- **S**tandards**—**the OH&S practice of setting acceptable exposure standards for hazardous substances (an inherently risk-based approach);
- **C**over**—**insurance industry risk assessment for providing cover and the increasing difficulties and expense in getting environmental impairment insurance cover;

- **A**ssessment—the development of ecological risk assessment.
- **L**ong-term exposure—the development of environmental health risk assessment associated with long-term exposure to pollutants; and
- **E**nvironmental awareness—an increased awareness by the community, industry and governments of the need to protect the environment.

The shift to performance-based regulation in environmental and related fields has also stimulated risk-based environmental management. The risk-based approach has been found to be necessary to show that all relevant issues have been considered and reasonable management measures implemented. At the same time, the process identifies cost-effective measures for dealing with the particular hazard and reducing risk to acceptable levels.

Of major importance has been the growing recognition by the mining industry, as by other industries, that, regardless of regulatory requirements, sound environmental management is essential to a sound business and that without ERM environmental management cannot be complete.

1.4 DEFINING ERM AND ITS ELEMENTS

There are a number of key terms and concepts used in ERM which need to be understood. Universal agreement on the definitions of some terms is lacking. The terminology differences stem from the diverse origins of risk management and the diversity of disciplines involved. It is generally easier to get cross-disciplinary understanding of the usage of a term in risk management than to change its usage within disciplines.

AS/NZS 4360:1999 *Risk Management* has attempted to develop standard definitions and these have been adopted where possible. In some instances, however, the AS/NZS 4360 definitions do not fit well with the ERM method described here and more suitable definitions have been used instead. The term 'environmental' has been left implied in several definitions for the sake of brevity.

Environment—encompasses all aspects of the biophysical environment, human health and well being, and community values. (See also discussion of scope in Section 1.2.) Due emphasis should be placed on ecologically sustainable development, as explained on page 6 of the *Overview* booklet in this series.

ERM and environmental risk analysis and assessment should not be confused with ecological risk analysis and assessment. Ecological risk is a subset of environmental risk that deals with flora and fauna and their relationship with the environment.

Hazard—a source of potential harm or a situation with a potential for harm.

Risk—this basic and important concept has two dimensions: the consequences of an event or set of circumstances and the *likelihood* of particular consequences being realised. Both dimensions apply to ERM with it generally being taken that only adverse consequences are relevant.[1]

***Hazard** denotes a potential cause of harm, risk describes the likelihood of the harm becoming actual.*

Risk analysis—the systematic use of available information to identify hazards and to estimate, quantitatively or qualitatively, the likelihood and consequences of those hazards being realised.

Risk assessment—the evaluation of the results of risk analysis against criteria or objectives to determine acceptability or tolerability of residual risk levels, or to determine risk management priorities (or the effectiveness or cost-effectiveness of alternative risk management options and strategies).

Risk management—the systematic application of policies, procedures and practices to the task of identifying hazards; analysing the consequences and likelihoods associated with those hazards; estimating risk levels (quantitatively or qualitatively); assessing those levels of risk against relevant criteria and objectives; and making decisions and acting to reduce risk levels.

Residual risk—the level of risk remaining after risk control measures have been implemented.

Harm—any damage to people, property, or the biophysical, social or cultural environment.

Consequence(s)—the intermediate or final outcome(s) of an event or situation.

Likelihood—a qualitative term covering both probability and frequency. The use of the more general term 'likelihood' can sometimes avoid confusion which arises from the common error of using 'frequency' and 'probability' interchangeably.

Frequency—the number of occurrences of a defined event in a given time, or rate. Frequency is expressed as events per unit of time.

Probability—the likelihood of a specific outcome measured by the ratio of specific outcome to the total number of possible outcomes. It is expressed as a dimensionless number in the range 0 to 1 with 0 indicating an impossible outcome and 1 indicating an outcome is certain.

Hazardous event/incident—an event/incident with the potential to cause harm.

Risk treatment—selection and implementation of appropriate options/actions for dealing with risk. Essentially the ongoing management of risk once it has been analysed and assessed.

Sensitivity analysis—the examination and testing of the results/outcomes of a calculation or model; or analysis by changing assumptions and/or the values of individual or groups of related variables.

As already mentioned, the usage and definition of some of these terms is not consistent. In particular, the terms 'risk' and 'hazard' are sometimes interchanged as are 'risk analysis' and 'risk assessment'. 'Risk management' is sometimes used to mean the decisions and actions downstream of the assessment and sometimes, as here, to cover the whole process. 'Frequency', 'probability' and 'likelihood' are also commonly used loosely. It is important for internal and external communication that there is a clear understanding of how each of the terms is being used, particularly when scoping a study or developing policies and procedures.

The ERM process is illustrated in Figure 1. Important features are the return loops from the risk assessment (and, importantly, the risk treatment) boxes to the hazard identification process. These return loops are essential as it should never be assumed that changes introduced to address a particular hazard or level of risk will inevitably deal adequately with that risk. An iterative process within the analytical stage may be required. At the very least, the sensitivity of the analysis undertaken should be tested on the basis of the system with the proposed change in place. Furthermore, as systems do not remain static, change management and periodic review are essential.

Figure 2 is an alternate depiction of the process. This figure emphasises that risk management is an iterative process, with a need to examine residual risks remaining after risk treatments have been applied. Often, the first comprehensive risk analysis and assessment process is the most intensive process. Subsequent review and revision may be a 'lesser activity', with risk treatment and monitoring dominating the later phases as the system is refined. Figure 2 emphasises the importance of communication in the risk treatment stage. Because this stage also provides the input to the risk identification stage, the communication of concerns is labelled with the instruction: Act! Such action happens throughout the ERM process, because each step of any risk management process requires a smaller scale version of the whole process. This is also true in risk appraisal, which deals with consequences and their calculations as well as risk assessment which deals with calculations, their likelihood, and their comparison with externally derived criteria. While the components may be labelled at points on the diagram, the 'wheels within wheels' nature of risk management means that *all need to be considered at all stages*. The nature of the task determines the intensity of the particular stage of the process.

1.5 PRINCIPLES OF ERM

Taking a risk management approach recognises this key, underlying concept: that uncertainty is a fact of operations, business, nature and natural hazards and the 'real world' in general. Perfect worlds exist in economists' models—the rest of us have to cope with uncertainty.

Uncertainty can be derived from, or be associated with, any aspect of a system. It can, for example, be associated with: unintended events such as spillage of a hazardous material; events that are inevitable and whose return period, timing and intensity is uncertain (such as earthquakes); or the effects of intended actions such as emissions to air and their consequent health effects.

Uncertainty can be divided into three categories, which have been termed the uncertainty of ignorance, the uncertainty of the unknown and the uncertainty of unpredictability. The 'uncertainty of ignorance' exists because the hazards and risks have not been investigated—you don't know because you didn't ask. The 'uncertainty of the unknown' exists because of the limits to our knowledge.

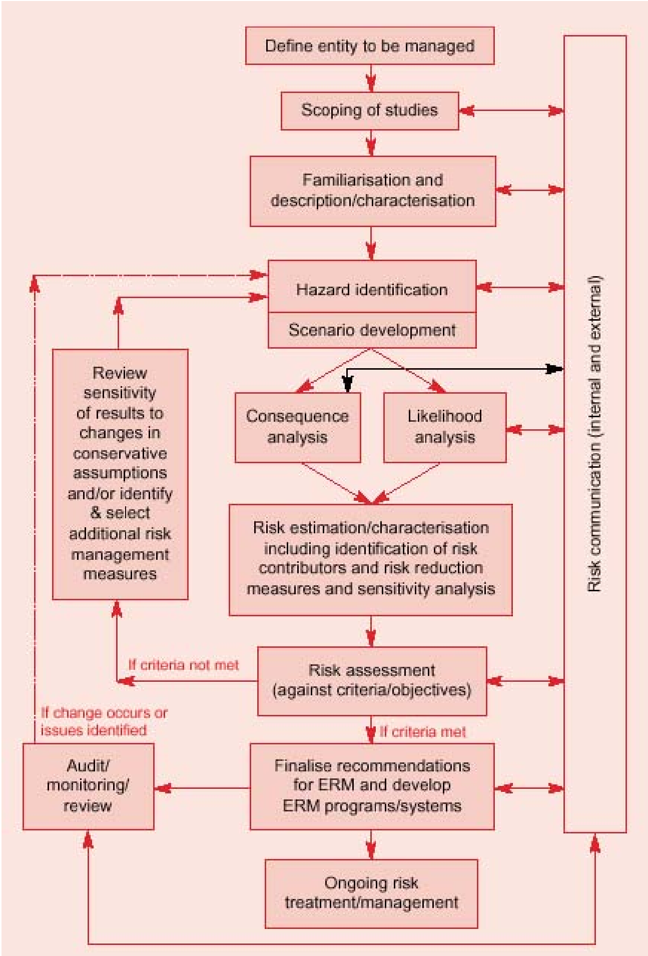


Figure 1

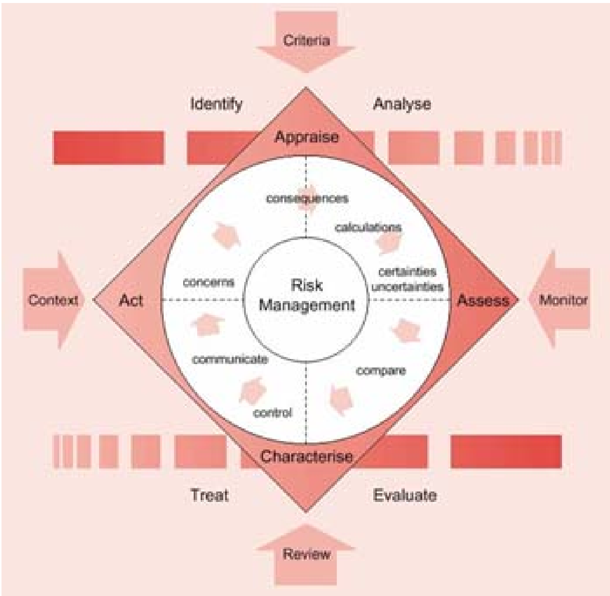


Figure 2

The precautionary principle is important in dealing with this type of uncertainty. The 'uncertainty of unpredictability' is due to inherent unpredictability (e.g. weather and earthquakes). For any aspect of a system the overall uncertainty may be a product of all of these types.

ERM should aim to eliminate the uncertainty of ignorance and identify and manage the uncertainties of the unknown and unpredictability. After a comprehensive risk analysis, while the timing and magnitude of all events will not be known, there should be sufficient knowledge to eliminate hazards, minimise their likelihood and/or minimise possible consequences.

ERM should be based on the following best practice principles:

- **Commitment and a formalised, structured, systematic approach**—ERM cannot be effective without real commitment from the organisation (especially from senior management) running the facility or operation being studied. This commitment is best demonstrated by ensuring risk management follows a formally adopted policy, with ERM procedures, objectives and management responsibilities clearly stated.
- **Covering all operations and its whole life cycle**—ERM should cover all the mining and associated operations, including transportation. Management responsibility for different aspects of mining and associated operations may be separate, or environmental risk management carried out by different organisations or different groups within the same organisation. However, the overriding aim is to *cover all aspects*. Also linkages between upstream and downstream stages of the mining process must be considered so that ERM or other management initiatives for one stage do not aggravate or create risk or other problems for other stages. The risk management process should encompass all stages of the mining process, from concept to decommissioning, monitoring and management in the post-mining stage.
- **Sound risk analysis**—any decisions or actions taken to reduce risk can only be as good as the analysis on which they are based—the identification of hazards and the analysis of the attributes of those hazards. Analysis must be comprehensive and rigorous, using qualitative and quantitative analysis as appropriate to the issues being addressed and the information available. Its scope must be well defined so it analyses its target hazards cost-effectively and comprehensively.
- **Integration of ERM with overall risk management**—if ERM is in its own separate 'compartment' it is unlikely to be ranked as highly as it should be against other business and regulatory compliance interests of a mining operation. Neither is it likely to be given the priority it deserves in the organisation's environmental policy and community relations objectives. If risk management is not integrated, measures taken to manage risks of one type are likely to unwittingly exacerbate another form of risk.
- **Integration of risk management with overall management**—risk management, while being recognised as having its own special characteristics, needs to be fully integrated with overall management of the facility and organisation. If not, risk issues are unlikely to be considered early enough in decision-making processes and risk management is unlikely to be given the priority it warrants. *This may have implications for future management, staff or operational costs.*
- **Integration with environmental management**—as well as being integrated with both overall risk management and overall management, ERM needs to be closely integrated with the environmental management systems. *Failure to do so may also have implications for future operational costs.*
- **Ongoing**—the risk management process should be a continuous process, not a single or periodic snapshot exercise. Organisations and operations undergo continual change, some resulting from management decisions, some by inertia

or 'accident' and some by outside forces. If risk management is not an ongoing process, it is unlikely that objectives set for risk-affected parts of the operation will be met. As the facility or operation—or factors in the wider environment—change, it is highly likely that new hazards with changing consequences and likelihoods will develop.

1.6 ERM AND MINING

Mining operations clearly have significant potential to cause environmental harm if not managed effectively. Mining can never have zero environmental impact: there is always some uncertainty about the probability of events and about the type and extent of possible adverse impacts from them. Risk management has a vital role to play in operations, because the likelihood of adverse consequences cannot be entirely eliminated without making mining operations technically or economically non-viable. ERM helps ensure that environmental risk is contained to acceptable levels while helping to ensure that management measures, controls and regulatory requirements do not impose unnecessary or inappropriate cost burdens.

ERM is well established in some industries, but still relatively new in the mining industry. Generally, the methods exist to deal with all the environmental risk issues in the mining industry, but some tools and models may need to be developed and refined for specific risk types.

ERM implementation varies widely in the mining industry in its scope, objectives and application. The quality of implementation has often been poor. In many instances it would seem to be significantly below best practice in other industries, such as the chemical and nuclear industries, and there would seem to be much room for improvement. As the application of the ERM approach in the industry develops and matures, a shift to more comprehensive analysis can be expected. It is likely that much of the work to date may need substantial revision as that shift occurs.

Regulatory requirements and processes (such as requirements to include risk assessments in EIAs for new mine development or expansion) are in part driving the move towards environmental risk assessment in the mining industry. The effect of performance-based legislation, which provides for corporate, director and executive liability, has also been a powerful impetus for making senior company officials and directors more risk-averse. Of increasing importance, however, is the recognition that a risk-based approach to managing the relevant issues can be a powerful tool in ensuring cost-effectiveness of environmental management and thus protecting the operation's bottom line. Financial and insurance industry requirements appear, in some instances, to be driving a requirement for more rigorous judgments on environmental risk exposures.

[*] see *Analysis and Assessment*

[1] The same approach and techniques could assess possible positive environmental impacts, but outcomes often arise from a negative impact resulting from an environmental management failure. As such, a study of negative impacts should cover them. Potential but uncertain positive environmental impacts may occur in some cases but these are usually regarded as incidental and are seldom the focus of analysis.

2. ERM METHODS AND PRACTICE

2.1 OUTLINE OF METHODS

Figure 1 shows the basic methods of ERM. Key elements are:

- defining the entity to be managed;
- defining the scope of study/ies—purpose, objectives and entities covered;
- familiarisation/description;
- hazard identification (including scenario development);
- consequence analysis;
- likelihood analysis;
- risk estimation/characterisation—including identifying risk contributors, opportunities for risk reduction and general sensitivity analysis;
- risk assessment against criteria and/or objectives;
- if criteria/objectives are not met, sensitivity of results to changes in conservative assumptions and identification of additional risk management measures are reviewed and a the hazard identification and analysis stages are repeated;
- if criteria/objectives are met, recommendations for ERM measures, strategies and programs/systems and development of those programs/systems are finalised;
- risk treatment—implementing recommendations and ongoing operations of ERM programs/systems;
- ongoing hazard auditing, monitoring and review and change management (including revisiting earlier analytical steps and adjusting risk management as change occurs and new information and understanding becomes available); and,
- risk communication—operating in parallel with the other elements of the process throughout.

As each of these elements flows into the next, the downstream analysis, assessment or management of environmental risks is limited by the quality and depth of work that preceded it. The effects of limited or inadequate work cascade through the subsequent stages with the impact on quality often snowballing. This directly affects the validity and efficacy of all stages of the ERM process.

The process description in the diagram and the points above are necessarily simplified. In practice, the initial analysis and assessment process is less linear. There is usually a degree of iteration in the studies and the stages can overlap and proceed in parallel. The analytical process also starts broad, then narrows as identified hazards are eliminated by considering consequences or likelihood of consequences. Often there are important links between the findings and recommendations flowing from the analysis and assessment and the assumptions on which the analysis is based. Findings and recommendations should be developed throughout the study. They should be brought together only at the end of the process. Effective communication between those undertaking the studies and those running the facility or operation is also vital throughout.

Within this methodological framework, different approaches and methods are possible. There are different schools of thought as to how, and how much, analysis should be undertaken but each of the elements needs to be present.

The methodological framework is applicable to both new and existing development though there are practical differences in application. Most notable is the extent to which design and operational features are entrenched at the time of the initial study. For established operations, this will reduce latitude to make changes without incurring significant costs. This difference highlights the benefits that can accrue from initiating risk analysis and assessment as early as possible when planning a new development or modifying existing operations.

In many instances, regulatory requirements will drive environmental risk analysis and assessment for new developments and major modifications through EIA/EIS processes. It is again important that risk studies begin early in those processes to allow time to complete and maximise possible input before submitting proposals to authorities.

'Analysis' and 'Assessment'

The terms 'analysis' and 'assessment' are sometimes used interchangeably in the literature on risk. There has been considerable debate about how each should apply to particular ERM methods.

Some view 'analysis' as embracing all that is done to establish an understanding of risk and its characteristics and 'assessment' as being limited to the comparison with criteria. Others see 'assessment' as the wider term and 'analysis' as a part of the process.

This debate is essentially semantic. The terms should matter little if all those engaged in a particular exercise have a common understanding of the methods being applied and the outputs they provide.

There is however a key issue at stake. The terms don't matter but the substance does. The very core of risk investigation, the part that adds value, is the analysis—the breaking down of the system being studied and its hazard and risk attributes into their constituent elements—and exploring, examining and testing those elements and their links.

When rigorous analysis is replaced by superficial processes, which tend to reveal only the obvious, the value of the exercise is diminished and risk management based on such work is likely to be misguided and inadequate.

The value of ensuring that ERM covers both strategic and tactical/operational aspects also warrants mention. Both the big picture and the detail can be important to sound ERM and this needs to be recognised in the definition of the overall exercise and the scoping of studies.

2.2 DEFINING THE ENTITY TO BE MANAGED

In an ideal world, every aspect of mining-related operations would be subject to ERM. In practice this is not so and it is unrealistic to expect to achieve this quickly. It is necessary therefore for ERM exercises to be more selective and focused and it is particularly important that, when starting any such process, careful attention is paid to defining the scope of objectives and the entity to be covered.

There are many reasons for initiating ERM. These may be largely internal or external such as by regulatory or other external requirements. If, for example, an EIA process for a new mine or mine extension includes the need for ERM, the scope may be prescribed or otherwise clearly set. Or the scope and objectives may be relatively ill-defined. The process may also be initiated, for example, by an incident or recognition that a critical issue needs resolving. Even when initiated for one purpose, it is worth considering the possibility that an ERM exercise may provide further benefits if other aspects of risk are included. Whatever the initiating factor, it is critical that all parties understand its scope and objectives.

Depending on the purpose and objectives, the exercise might extend across several operations or be limited to a single mining operation (or perhaps a division of the organisation). Operationally, it might be confined to a primary extractive operation or extend to downstream processing and transport operations. It might be confined to a particular mining phase, in recognition of issues or conflicts that might be limited to that phase.

It is also possible that the specific ERM exercise might be confined to a particular hazard or set of hazards or to a particular consequence or class of consequences.

When the ERM exercise is limited to part of an organisation, operation or facility, it is appropriate to establish the organisational or operational context of the entity to be managed and define its boundaries. This is particularly important when ERM is new to the organisation and helps ensure the scoping of the ERM (and also subsequently of the study/ies undertaken as part of the process) is appropriate for both inclusions and exclusions. The clear definition of the entity also helps to ensure that the fact of the limited scope is not lost and that excluded parts of the whole will be returned to as necessary.

2.3 SCOPING OF THE RISK ANALYSIS

There may be a need for a number of separate studies within the ambit of a defined ERM exercise. The careful scoping of these studies is again an important issue. Often there will be time and resource constraints on particular studies. The scope and the methods selected in undertaking the studies needs to match those constraints. It must be recognised, however, that limiting the study will affect its quality and the value of the outputs. Whether the study is preliminary or more final should also be addressed in the scoping.

However much the scope of separate studies is limited, they still need to each deal with the interactions and dependencies between the particular part of the operation or system being studied and other parts of the same systems and external systems. The boundaries must allow for such factors to be considered and every effort should be made to set them to encompass logical assemblages.

In parallel with scoping, the methods and personnel for the study should be selected or reviewed. All those who will be responsible for the study and those who will have a major role in it should ideally have some opportunity to have input to the scope before it is 'set in stone'. As the scope, resources and methods will all affect one another, the process may need to be iterative.

2.4 RISK ANALYSIS

The next five elements of the process comprise risk analysis and are shown in Figure 1. Sensitivity analysis, that is, the identification of risk contributors and of risk reduction options also fall within the analytical process, but this analysis may be done after or during the assessment stage.

Risk management cannot be better than the analysis on which it is based—if based on good analysis it can still be poor but if the analysis is bad it cannot be good—except by unlikely lucky coincidence.

2.4.1 Familiarisation and Description

Becoming familiar with a system and, its environmental and operational context, and developing a description of it, constitute a crucial stage of the analysis. The extent of work necessary for this stage will vary with the approach of the responsible personnel and the level of detail needed.

It is essential not to take this step for granted. If people already familiar with a system study it, it might seem that little action is needed to become formally familiar with it. Experience shows, however, a surprising degree of variability in individual knowledge of different aspects of a system. This includes inconsistent understanding of the design and workings of physical equipment and infrastructure and of operational procedures and practices. Fundamental insights are often gained from this stage of the analysis and recommendations often flow from it.

Photo: Graham A Brown & Assoc

Hazard identification is a crucial step in the ERM process. Indications of acid drainage problems are being discussed.

If people less familiar with the system are to study it, such as company personnel from head office or another facility, or consultants, then familiarisation is even more important.

Having analysts prepare a formal written description is often of great value as it tends to force them to understand fully and with greater precision the mining operation under study. It also enables their understanding to be tested/verified against the reality of those who actually operate the system. All features of the mining operation itself as well as the relevant environmental context need to be fully described. The environment considered may extend for a substantial distance from that on-site. This means the possibility of harm arising from mishaps (such as river systems becoming contaminated) to be taken into account. The description should encompass not just physical features, such as layout and equipment, but also operational practices and features, and organisational structures and responsibilities.

Becoming familiar with the system and developing the description are also necessary for structuring the study. Studies can be structured in various ways. For example, they can be organised around the operational steps in a mining process or around operational areas or equipment systems. It is also often appropriate for the stages of the mining process to be considered. These aspects may be combined in different ways but a logical and systematic structure is essential to ensure all aspects of the system being studied are covered. The structure must therefore allow for interconnections (e.g. services, equipment, communications etc.) and must ensure that the 'odds and sods' that are not considered mainstream, or for other reasons do not fit neatly into a particular structural compartment (e.g. cleaning and maintenance operations), are not overlooked.

The familiarisation process would typically be based on a review of documentation including, drawings and maps, procedures, reports on previous studies and investigations including EIA documentation, and audit reports. For existing operations, an audit-type inspection might be an important input to the familiarisation and, for both proposed and existing operations, an inspection of the surrounding environment would generally be essential.

The system description must be thorough and comprehensive, within the confines of the scope, or it will not be possible for the hazard identification to be complete. The importance of getting these initial stages of the analysis right cannot be overemphasised—they are the foundation on which all else is built.

2.4.2 Hazard Identification

Hazard identification should be a structured process which systematically works through the elements of the facility or system being studied (as identified in familiarisation/description process). This will maximise uncovering all events and circumstances that could lead to significant adverse outcomes. For each selected element of the facility or system, careful consideration should be given to:

- possible initiating events or circumstances;
- consequences of those events or circumstances;
- available technical, operational or organisational safeguards or controls;
- the likelihood of the initiating event or circumstance arising; and,
- the likelihood of its translation into significant adverse outcomes if safeguards and controls are used.

This logic is illustrated in the sample hazard identification word diagram (Appendix 1). The logical sequence can be seen in the column headings and the steps for the element of the facility shown.

The essence is that the identification starts out with a pessimistic view. It is assumed that what can go wrong, will. Cases are only eliminated when it is clear that, because of safeguards and control measures or with further consideration of the nature of the hazard, either the consequences would not be significant or the likelihood would be too low to warrant further attention.

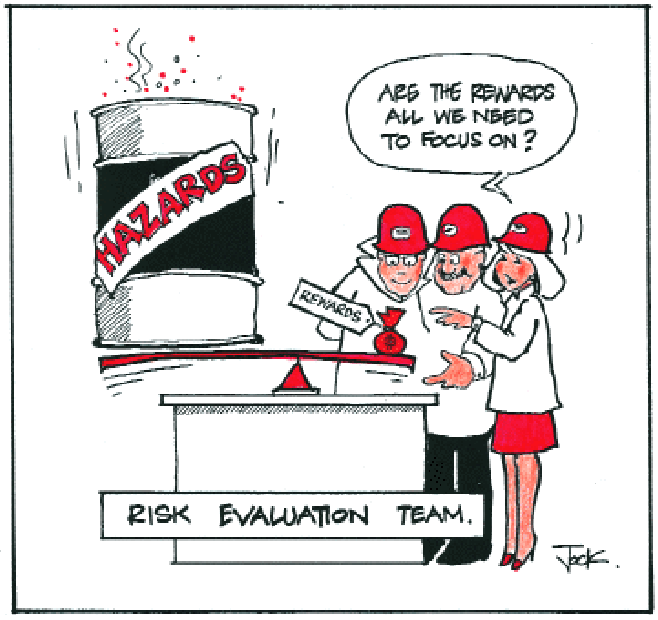
The identification process must try to penetrate beyond the obvious for every element of the process. People are usually aware of the obvious hazards and believe there are measures in place to deal with them. Even for more obvious hazards, however, people familiar with a facility or system often overlook system features with serious hazard potential. It is perhaps even more common for people to underestimate the consequences if addressing the hazard might be, or appears to be, inconvenient or expensive. The dangers of this attitude are often exacerbated through people overestimating the effectiveness of a system's safeguards and controls.

A major part of the value of formalised risk analysis and assessment lies in revealing hazards and providing a basis for judging whether the measures in place to address those hazards are appropriate. Any process that tends only to reveal the obvious is inadequate and potentially misleading/harmful. It is often the less obvious hazards and contributors to the likelihood of their realisation that are most likely to expose an organisation to risk.

The hazard identification needs to encompass:

- hazards to all potentially affected aspects of the environment including but not limited to:
    - surface and groundwater (including diversion of flows);
    - air (dust, smoke and fumes);

    - the atmosphere (greenhouse or ozone depletion impacts), natural areas and flora and fauna including vulnerable species and ecosystems;
    - heritage items including aboriginal heritage items;
    - forestry, agricultural and pastoral land, and their animals and crops;
    - soil (contamination, erosion; degradation);
    - geological structures (surface or sub-surface);
    - aquatic ecosystems and fisheries;
    - man-made structures;
    - human health and safety; and
    - aesthetic and cultural values.
- all types of hazards including:
    - fires;
    - explosions;
    - releases of toxic or polluting materials;
    - changes to runoff and water flows;
    - introduction of exotic plant and animal species or pathogens (e.g. through ballast water at mine-product loading facilities and plantings for rehabilitation of sites, or truck or heavy equipment movements);
    - subsidence; and
    - dam failures.
- the whole of the mine life cycle including exploration and rehabilitation (impacts from, for example, e.g. spoil heaps or tailings and acid drainage could be delayed or long-term.
- the whole of the area or systems potentially affected, i.e. not just the local environment if impacts could extend further afield.
- the whole of relevant operations as defined in scoping, for example, transport of treatment chemicals and explosives to a mine site as well as the ore from the site by road, rail and ship, and associated loading and treatment facilities.
- continuous emissions, not just accidental releases—the uncertainty making this a risk issue may be related to consequences of the emissions at intended levels not the uncertainty as to their release. The impacts of other intended operations should also be covered, for example, impact on wildlife populations from road kill or higher incidence of bushfire (control burns or wildfire).
- all types of causative factors including natural events (for example, storms, earthquakes) if they can lead to incidents able to harm the environment.
- perceived hazards and controversial issues.
- wastes and by-products, as well as the mined materials, and materials used in mining and associated operations.



Typical examples of environmental hazards that might be encountered in mining industry operations are set out in the box below. The list is representative, not exhaustive, and should not be used as a checklist. Factors will change from site to site. As can be seen from the listed items there are links and interactions between them and an event causing a hazard of one type might lead to one or more other hazards e.g. subsidence followed by a dam failing and tailings being released.

Various methods are available to identify and evaluate hazards. There are also different ways to present the information. When word diagrams are used, explanatory text is generally added to expand relevant aspects.

Some methods rely on an individual or small team to develop the hazard identification. Then, best practice means having it reviewed by others with a different perspective. This particularly applies when those identifying the hazard are not operationally associated with the facility or system under consideration.

Mining Industry Operations—Typical Environmental Hazards

- clearing vegetation (loss of rare species or habitat)
- soil disturbance (wind and water erosion and dust)
- acid sulphate soils
- blasting (explosion, dust and vibration)
- mullock/waste rock and slag (instability, leachate and dust)
- subsidence (impacts on heritage items and natural and man-made structures)
- radioactive tailings
- potentially toxic tailings (acid leachate, heavy metal or saline)
- saline or other contaminated waters from mine workings
- contaminated stormwater runoff
- storage, handling and transport of fuels or process chemicals (spillage, fire, explosions etc.) and/or containers
- disruption of surface or groundwater flows (including collection for use, diversion and increased runoff)
- storage and handling of explosives (unintended explosions)
- exotic species and plant, animal or human pathogens (introduction through transportation operations or rehabilitation planting etc. or change to habitat)
- bushfires (increased frequency from more ignition sources)

- processing, storage, handling and transport of mined material and processed material (fire, explosion, spillage, dust etc.)
- continuous/intended emissions to air or water (e.g. smelter emissions, dust discharges)
- containment and service structures (e.g. tailings dams or water supply dams, product or supply pipelines, conveyor belts)
- inadequate security—sabotage etc.
  mechanical failure (e.g. burst pipes, ruptured liners)
  human error (e.g. poor or careless bund management)
  accident (e.g. vehicle collisions, roll overs)

Sometimes, for instance in a Hazard and Operability study (HAZOP), a brainstorming approach is taken and this can allow direct participation by all relevant parties—including consultants, designers, manager and supervisors, operators and external specialists.

For simplified approaches to risk assessment using qualitative rapid ranking, a hazard may be identified using a brainstorming process that also incorporates the later steps of the analysis into a single exercise. As indicated below in the discussion of qualitative and quantitative approaches, while such exercises have their merits and may sometimes be appropriate, they can also have significant shortcomings.

The **overall hazard identification process** may in practice have multiple inputs. These might include:

- an **audit-type inspection**;
- **brainstorming sessions** with relevant parties (which might take the form of a HAZOP or 'What If' analysis or might be less structured).

and **reviews** of:

- **community concerns** or issues raised in objections to a development or in a formal consultation process;
- licence and condition **compliance and breaches**;
- **incidents** in the particular facility or system and in like systems or other parts of the same company;
- operating, maintenance and emergency **procedures**; and
- any **previous audits** and studies.

Particularly for complex systems, the process might use logic trees (fault and event trees) to identify relationships and outcomes and might also use some form of failure, mode, effect analysis (FMEA) to identify consequences. In some circumstances, other analytical approaches such as cause (consequence analysis and human error analysis might also be used. These methods might not be applied to their full extent (e.g. likelihood quantification) for this part of the analysis, but be used to determine relationships and sequences and to build representative scenarios.

Hazard identification methods should be tailored to the specific study but they must be comprehensive and draw on as many sources of input as possible. An environmental audit can help identify hazards and, where such audits have been previously carried out, they should be drawn on. An audit should not, however, be seen as the sole basis for hazard identification and certainly not as a substitute for rigorous risk analysis.

While it is important to use the hazard identification process as a filter to eliminate all aspects of an operation that do not pose a credible or relevant risk, it is also very important not to discard a subject from the analysis too soon. This can be a serious problem when using rapid risk assessment techniques not just to rank suspect aspects of an operation but to eliminate matters from further consideration.

The risk management process is not simply about dealing with what is sometimes termed the 'actual' or 'real' risk—the level of risk estimated by a risk assessment process or that believed to exist as a factual entity from a technical point of view. Rather it is about ensuring that all relevant risk issues are addressed. Issues identified by the community and controversial, or likely to be controversial, warrant examination by the hazard identification and ERM process. The hazard identification process should therefore consider all hazards of community (and workforce) concern and should be careful not to set them aside without clearly demonstrating that they will not pose unacceptably high levels of risk.

It should be noted that, even when hazards are thoroughly identified some aspects may have to be re-examined as matters become clearer during consequence or likelihood analysis, or even in the risk estimation or assessment.

At the end of the hazard identification process, those matters that warrant further detailed examination should be flagged and (where appropriate) scenarios developed for further examination.

Scenario Development

With any complex system it is not possible to examine every possible risk in all the myriad variations. Careful scenario development does, however, enable most risks to be reasonably covered by representative scenarios. All cases that emerge from the hazard identification process as significant should be covered by the scenarios carried forward for further analysis.

In detailed risk analysis, particularly when risks are to be fully quantified, the scenario development is an important part of the analysis. This process requires deconstructing the hazardous event to its constituent parts so that consequences and likelihoods of the components can be analysed separately. Logic trees such as fault and event trees are often used in this process. (See example fault and event trees in Appendices 2 and 3.)

Deconstruction can be a powerful way to analyse more deeply by focussing on individual contributors to overall events. This allows weak links to be identified and, later in the analytical process, sensitivity analysis and the identification of contributors to risk can be undertaken rigorously.

2.4.3 Consequence Analysis

Analysing consequences encompasses not just the end outcomes but the steps leading to the outcomes. For example, for the effect of a storm event on a tailings dam, the consequence analysis could cover:

- the consequences of the storm on the volume of water received by the dam, the extent of overflow and the possibility of failure;
- the consequences of contaminants being released and their concentrations/durations in receiving waters after a breach or overflow; and
- the consequences of those concentrations/durations on species and ecosystems.

For each element, several aspects might need to be considered. These could include magnitude, extent, severity, duration. Developing an understanding of where the initiating event may lead is typically dealt with in this part of the analysis. For simpler analyses, this may be able to be dealt with in the hazard identification and scenario development. However, for more complex, unusual or unique analyses, the extrapolation of the scenario, except in the most general terms, cannot be completed before the more detailed analysis.

Consequence analysis is always a mixture of the quantitative and qualitative. Some components will be able to be measured, estimated or projected with relative precision—others will necessarily rely more on qualitative analysis. The limits to knowledge and modelling capacity generally grow with each step from initiation to ultimate consequence. Therefore, a greater element of estimation and qualitative analysis becomes necessary for the later stage effects. This is particularly true when natural ecosystems are involved.

Analysis of consequences through to the 'end state' is often too difficult and time consuming and the inherent uncertainties too great. Consequently, the usual approach is to carry the analysis in detail to some intermediate point. For the storm event discussed above, analysis might end after determining likely concentrations and durations in receiving waters.

Conservatism in analysis and assumptions is often warranted, given the uncertainties and limits of knowledge. The precautionary principle (see *Overview* booklet, p7) should then be observed.

Worst case analysis is often used to test the limits of potential impacts. If worst case assumptions indicate no serious potential for significant impacts, then that particular issue can be laid to rest. But, if problems are shown under such assumptions, the sensitivity of the analysis to changes in assumptions, and how the conservatism of those assumptions are justified may need to be examined. Alternatively, it may be preferable to consider changes to the operations or the implementation of cost-effective safeguards.

Depending on the nature of the event(s) or impact(s) being considered, it may be appropriate for the analysis to extend to second-round effects and beyond. For example, discharge of a toxin to a water body might only affect a single plant or animal species but the effect on that species may disturb the whole ecosystem by disrupting the food chain. While there may be real limits to the practicability of analysing second-round effects, the possibility of significant impacts beyond those directly and immediately felt should always be considered.

Risk analysis is by nature multidisciplinary. Depending on the hazard, a wide range of disciplines may contribute to analysing consequences. These include: civil engineering (e.g. for dam or other structural failure); chemical engineering (e.g. for hazardous materials handling); hydrology and geology (e.g. for ground and surface water assessment and soil stability); air and water dispersion modelling (e.g. for dust and chemical releases); toxicology (e.g. dose response, exposure); ecology; ecotoxicology; and human health impact assessment (particularly for dust emissions and continuous emissions to air).

Photo: Richard Heggie Associates Pty Ltd

Measuring the impacts: blast monitoring underway—testing vibration levels on a sheetpile wall.

A wide range of analytical methods and tools are available for consequence analysis. For some hazards, sophisticated mathematical modelling (computer programs and software packages etc.) may be available, while for others the techniques relevant to ERM may be much less well developed.

Each discipline will have its own analytical and modelling tools. As well as models publicly or commercially available, there are others that have been developed by individual practitioners and consultancies. Analysts need to be able to assess the applicability and limitations of the various tools before selecting or using them.

The analysis may call for a wide range of data inputs. Data would commonly include (but by no means be limited to): meteorological data (e.g. wind speed, direction and stability; rainfall intensity, duration and frequency; evaporation or evapotranspiration; temperatures); geological stability (e.g. earthquakes, subsidence, landslip); geology, hydrogeology and hydrology (permeability, pH, groundwater characteristics and flows, surface water flows); ecology (e.g. species present and habitat requirements); chemical properties (e.g. toxicology, physical state, solubility, reactivity). Some of the data sets used for the consequence analysis will also include information relevant to the likelihood analysis.

In some instances there may be existing data in the precise form required. In others, surveys and investigations may be needed to develop the relevant data. It would be commonplace for available data to require extrapolation or manipulation.

Collecting adequate data might take considerable time. Therefore risk studies critical to an approval process or other decision or action path should start as early as possible. In some instances, data may not be available and might take years to develop. But it may be possible to work around the missing data by using conservative assumptions and applying the precautionary principle. Data collection and further analysis may then proceed as elements of environmental monitoring and management under the ERM program or EMS.

Qualitative severity scoring by groups or individuals is sometimes used in lieu of more rigorous analytical processes. Such scoring is often part of the same process that allocates likelihoods. These exercises often use a matrix and descriptors such as those set out in Appendix E of AS/NZS 4360:1999.

For simple risk analyses, such an approach may be productive, especially when factors such as outcomes and their possible severity are well understood. For more complex and uncertain hazards, qualitative severity scoring tends to obscure rather than reveal. This is because judgments are based on existing knowledge and perceptions of the scorers rather than on a critical examination and exploration. The qualitative scoring approach is generally of some value for ranking but cannot add the insight that more detailed analysis offers. The features, merits and limitations of such qualitative approaches are discussed further in Section 2.4.9.

2.4.4 Likelihood Analysis

The likelihood analysis encompasses the likelihoods of each step in the train of events. These likelihoods include:

- initiating event frequencies;
- probabilities of specific safeguards failing on demand;
- the likelihood of an event causing a primary failure also causing safeguard failure;
- the likelihood of events coinciding and causing a different outcome from one event alone;
- likelihoods for human errors and appropriate and inappropriate responses;
- likelihoods of certain weather conditions (wind speed, direction, rainfall intensity/frequency/duration; and
- fatality/injury probabilities—for people and other species.

Logic trees (commonly fault or event trees) comprise an analytical method often used to develop an appreciation of the component inputs to events or outcomes of concern. As discussed in hazard identification and scenario development, these can be very powerful in getting the sequence of events right and establishing the role and relationship of the variables affecting the outcome. They are also invaluable as a basis for allocating numbers to those variables and subsequently for testing the sensitivity and isolating risk contributors. While their latter role is important for quantitative studies, the role of logic trees in sorting out the logic and interrelationships, even when the exercise is limited to qualitative analysis, should not be underestimated.

Detailed quantitative analysis deconstructs the system into its component parts and looks at whole systems thus allowing deeper analysis and the testing of sensitivity to changes in inputs and assumptions.

As with the consequence analysis, data sources can be many and varied. As mentioned in the consequence analysis section, some of the same data sets may be drawn on for the consequence analysis and the likelihood analysis (e.g. rainfall intensity/frequency/duration data). Additional data will however generally be required, including data on component or system failure, human error/reliability, event and weather frequency, toxicological probabilities, earthquake return periods, bushfire frequency and so on.

There are well established databases for items such as equipment components (e.g. pumps and valves), based on industrial experience. For other analyses, quality data will not be available and (as in consequence analysis) some work may be needed in compiling, manipulating or extrapolating data. In such circumstances, conservative assumptions, the precautionary principle and testing the sensitivity of the analysis to changes in values may all become particularly important. Whatever the source, considerable care in selecting data is needed as the output can be corrupted by inappropriate selection/generation of frequencies and probabilities.

By referring to experience in other industries, regions or countries, basic data may be gathered but care is needed to ensure the data applies to the circumstances of the case being studied. Experiences of the particular facility or company, including incident and 'near miss' incident information, should always be drawn on when available.

If other independent and applicable data is not available, it is often appropriate to draw on the experience of facility or company personnel to derive frequency or probability estimates for particular variables. The emphasis here is on *the particular variables*, not the overall incident or outcome likelihoods. Various techniques including questionnaires, interviews and group sessions can elicit this information.

Experience suggests that people generally give much more accurate and consistent responses on the component likelihoods than for the system and outcomes as a whole. This again is an advantage of breaking systems down to their variables. Major discrepancies often occur between likelihood estimates depending on whether they are for an overall event or outcome, or for component variables. This is shown if the estimates made by individuals or groups for component variables are combined and then compared with their results for the overall event or outcome. The components, and experience of problems or component failure, are usually much better known as they are part of the real daily experience of the mine personnel, whereas the whole sequence leading to an undesirable outcome is not.

2.4.5 Risk Estimation or Characterisation

Risk estimation or characterisation requires the consequence and likelihood analysis outputs to be combined so an estimate or indication of the likelihood of defined adverse outcomes can be generated. Risk estimation is the term usually applied when the analysis has a substantial quantitative component. Characterisation is usually applied when the work is substantially qualitative.

Risk estimates are commonly expressed as the chances per year of the defined outcome (which may be an end state or an intermediate outcome), for example one in a million per year chance of fatality at a specified location. The quantitative risk estimate can, however, be described in many ways. For example, as the likelihood of an event or outcome per operating month or year, as per tonne of output, or even as per export dollar earned or person employed. Sometimes, such as with a sensitive ecosystem or catastrophic event, or the introduction of an unstoppable exotic species, the relevant measure may simply be a probability of occurrence within the life of the operation. In some circumstances, the measure of risk might need to be developed to meet the special or unique circumstances of the particular case.

Qualitative outputs may be described by rankings such as very low to extreme risk. These rankings are based on combinations of high or low severity and high or low likelihood or by pairs of descriptors such as high severity/high likelihood, likely/minor or very unlikely/catastrophic. Numerical scores are also sometimes applied by adding or multiplying the allocated consequence and likelihood scores.

It is usually appropriate to establish the criteria or objectives to be used in the assessment stage early in the process, otherwise the indicators derived may not be the most relevant. The final selection of criteria might need to be deferred if limitations to risk results influence the possible criteria to be used. For obvious reasons it is essential that criteria and objectives be adopted, at least in principle, before moving on to risk estimation.

Risk may be for individual or groups of outcomes. Generally, it is appropriate to provide cumulative risk results when the outcomes can meaningfully be summed. It should not be assumed, however, that risk levels for an operation can be reduced to simple numerical statements, especially when the biophysical environment is at risk.

Even for something as relatively straightforward as human fatality risk, there are various ways to consider and present the information. For example, the two most common ways of presenting human fatality risk—individual fatality risk and societal risk—can produce dramatically different pictures.

'Individual fatality risk' is the risk a hypothetical person would face, if present at that location for the whole of the relevant period. Consequently, it says nothing about actual risk exposure as it does not imply that anyone will be present.

Societal (or group) risk on the other hand takes account of the population that might be exposed to particular incidents. Where there is a low population density, the societal risk outcome may be quite acceptable even for incidents with far reaching effects. For high population densities, the societal risk outcome might show an operation with an event consequence that is much more spatially confined to be quite unacceptable. In each case, the population density would have no impact on the individual risk results except through applying assessment criteria that might differ for different population densities or landuses.

Quantified risk levels can be graphically presented in several ways, such as:

- risk contours (isolines) and variants such as three dimensional depictions and colour bands and gradients when risk impact covers an area; and
- various forms of graphs including societal risk curves.

Results can also be tabulated, especially when risk contributors are identified and ranked. Alternatively the results can be described in text. Combining both text and graphs/tables, explaining key assumptions and limitations and interpreting the meaning of the results is usually appropriate.

2.4.6 Identifying Risk Contributors

One of the most useful outputs of estimating risk is the identification of the aspects of the system that contribute most to risk. This provides the opportunity to rank matters for action and to identify cost-effective risk-management measures.

Identifying risk contributors and developing cost-effective management measures are both easier using the fully deconstructed and quantified approach. By looking at the parts rather than the whole it is much easier to precisely target risk management measures. The quantification facilitates identifying, and focussing on, the most sensitive variables and testing of the effects of risk management initiatives on the 'bottom line risk levels' When combined with cost information, the various risk management options can be ranked in order of cost-effectiveness. It is also possible to identify the most cost-effective *combinations* of measures instead of being locked in to dealing with the higher risk contributors as separate items.

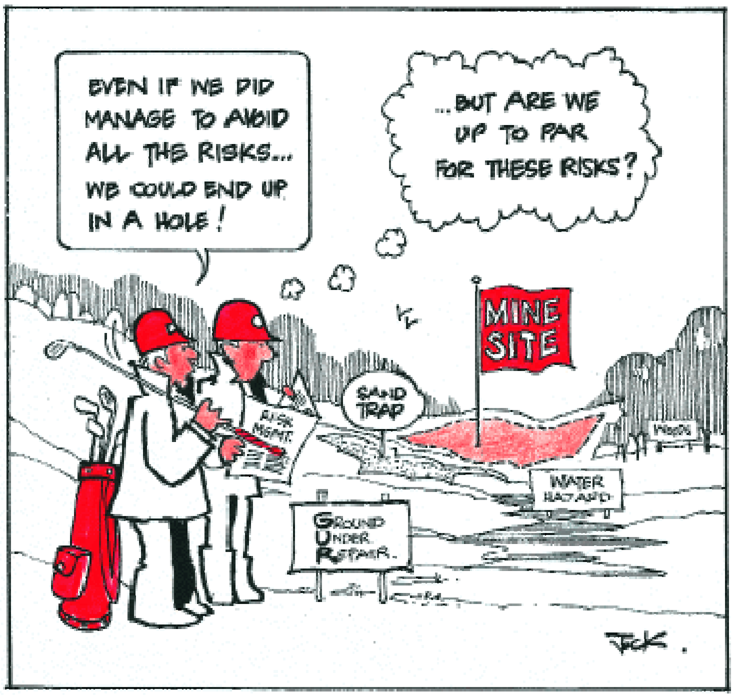
As with other stages of the risk analysis and assessment process, the sequence of the steps may vary from the simplified picture in Figure 1. The extent to which identification of risk contributors is needed may not be known until the risk levels have been assessed against criteria and objectives.

2.4.7 Identifying Opportunities for Risk Reduction

Opportunities for risk reduction can be found throughout the analysis. In the process of identifying risk reduction opportunities, hazard elimination (e.g. using a non-hazardous processing chemical vs. a hazardous one), reduction of potential consequences (e.g. reducing inventories or adding safeguards) and reduction of likelihoods (e.g. more frequent maintenance or monitoring or additional safeguards) should be considered.

A broad view should strive to encompass, as well as changes to operational details or safeguards, changes to basics—for example, the location of surface facilities, the mining or processing technology, or modes of transport of product.

Risk reduction can often be achieved at little cost and, in some instances, lead to substantial operational or capital cost savings (e.g. substituting processing materials or reducing materials inventories). For new developments, ERM is likely to be most cost-effective if initiated early and kept under review as the design and operational features change.



It is important for the overall ERM of a facility that risk reduction should be embraced as a philosophical objective so that options for the lowest levels of risk are pursued whenever they are achievable at affordable cost. This concept is embraced in the criteria referred to as ALARP or 'avoiding avoidable risk' (see section 2.5.1).

The identification of risk reduction opportunities in the analytical process is concerned with possibilities and their likely impacts on the risk levels and profile. Implementation is part of risk treatment and is discussed in section 2.6.

2.4.8 Sensitivity Analysis

As knowledge is usually significantly limited and modelling inherently imprecise, calculated assumptions (based on experience) have to be made during the analysis. Estimated or assumed values may need to be used for some variables in the consequence or likelihood analysis. While using conservative assumptions gives some assurance that risk is unlikely to be underestimated, it is important to test how changing assumptions and values affects the analysis. This should start with hazard identification (or perhaps even at the scoping and familiarisation stages) and continue throughout the analysis and also be part of a more formal review process at its end.

The implications of changes to assumptions and limitations to knowledge should be constantly considered, right from the outset. Such consideration needs to be incorporated into each step or important insights will be missed. If unresolved issues are discovered later, having to revisit steps of the analysis will cause delays.

While sensitivity analysis is possible when a qualitative approach has been pursued, it will generally be more difficult and less productive than when a quantitative approach has been followed. This is especially true when logic trees are used. The use of logic trees also adds strength to the analysis by addressing simultaneously confidence/certainty issues and the identification of contributors to risk.

One particularly powerful form of sensitivity analysis can be undertaken with fault trees and event trees. As the logic trees build by levels towards the top event (fault tree) or final outcomes (event tree), it is possible to select indicator points in the lower or earlier levels and evaluate the predicted experience against the actual operational experience. The top events and final outcomes happen less frequently than reaching the various points in the process leading to those end events. When there is an existing operation, this tool can be used in the initial analysis. For both new and existing cases it can serve as an ongoing monitoring process throughout the operation's life, providing early warning of system failures or analysis shortcomings.

When testing the sensitivity of variables in logic trees, it is necessary to be particularly aware of mutual dependency of variables. Changing single variables without adjusting to those which are mutually dependent with that variable can seriously compromise the conclusions.

There are a range of statistical tools for multivariable sensitivity analysis and, in some instances (particularly where the facilities are complex and uncertainties high) it may be worth using them. They are generally valuable only when the underlying analysis is sufficiently detailed and sophisticated. Time, cost and knowledge limitations commonly preclude the more sophisticated forms of sensitivity analysis and the added value in pursuing such finesse is sometimes questionable.

2.4.9 Quantitative and Qualitative

The discussion above has followed the classical risk assessment methods. Sound analysis includes both quantitative and qualitative components. The extent and proportions of different types of analysis may vary considerably. Lack of data (or similar problems) sometimes drives this but time, cost or resource limits may also preclude a more fully quantified analysis.

There is little doubt that, when possible, detailed quantified analysis by competent people, provides greater insight and opportunities for quality risk management than purely qualitative analysis. The strength of the quantified approach lies not in precision but in forcing a more rigorous analysis.

The greater degree of rigour and structure enables sensitivity to be tested, risk contributors to be identified and the impact of specific risk management options to be tested. The rigour of deconstruction in the quantified approach also tends to reveal matters left obscured by more superficial exercises.

There are, however, limitations to quantitative analysis. It should not be undertaken for its own sake but only when it adds relevant information or clarity—this may include a capacity to demonstrate clearly to third parties how results were arrived at.

A pitfall of quantitative analysis is an unjustified belief in the accuracy of the numerical results generated. These are not absolutes—the outputs of the analysis are based on imprecise information and necessary generalisation, simplification and assumptions. Indeed, it is sometimes argued that the term *quantitative* is inappropriate as it implies measurement and precision and that 'quantified' might be more suitable as it implies the more appropriate concept of estimation and approximation.

Qualitative methods are similarly vulnerable. The outputs cannot be better than the inputs allow and great care needs to be exercised in using those outputs. They are not, and can never be, statements of fact.

Wholly qualitative analysis techniques such as rapid ranking (based on sets of generalised analysis) and matrix based exercises have their place but should not be used to avoid rigour. They are of value principally for complex systems and manifestly inadequate risk management. In this role they can be used to effectively identify and rank some of the more obvious problem areas and to help set priorities for more detailed work.

Because of their limitations, they should generally not be used to exclude hazards from further consideration but only for ranking. Furthermore, unless the qualitative analysis has been based on separate and rigorous hazard identification—not always the case when matrix-type, brainstorming approaches are used to conduct the whole analytical process in one step—the likelihood of missed hazards should be recognised.

Audit-based exercises are sometimes referred to as risk assessment or analysis but are essentially an opinion by an auditor on which facility features pose some hazard or risk. Apart from these, the most common forms of qualitative analysis use a matrix approach.

The matrix uses consequence as one axis and likelihood as the other. The analyst or group ranks the hazard for degree of consequence and likelihood. Qualitative descriptors for consequence and likelihood as used in such a process are illustrated in Appendix E of AS/NZS 4360:1999. A matrix is also shown in that appendix.

Matrices sometimes have as few as three levels on each axis but more commonly have five. Experience suggests that five levels for each axis should be the minimum because participants find it difficult to decide on a rank with the smaller number of choices. The 5 x 5 matrix has 25 boxes which are then typically categorised into four or five different levels of risk—for example, low to high or very high.

In grids with more cells the scores are sometimes generated by adding or multiplying the levels on the axes. This can be useful in some complex systems for which other analytical tools are unavailable, but it can also falsely inflate accuracy/precision.

2.4.10 Using Outside Expertise and Resources

Environmental risk analysis/assessment is multidisciplinary. Depending on its type and scope, an exercise may require inputs from many different individuals and disciplines. Some of the necessary expertise and capability will be available from within the mining organisation or associated entities but some outside expertise or resources are usually needed, unless an organisation is large enough to establish and maintain internal specialist groups. External expertise or resources may be required for a specific technical discipline or for risk assessment. The need for specialist technical information on matters such as meteorology or ecotoxicology is often well understood. The need for specialised risk expertise is not always so well appreciated.

Risk assessment/analysis practitioners are often better equipped for quality risk analysis than mining company personnel, who generally have limited exposure and thus less experience. Organisations with specialist in-house capabilities may be the exception. External experts may also be more independent which may be particularly relevant in studies for regulatory purposes or where public confidence is an issue. They may also promote cross fertilisation of ideas—drawing from experience in other industries and mining operations or facilities. Even larger companies with their own risk assessment capabilities may find it cost-effective to call on external expertise for the benefits of independence and freshness.

External resources can offer greater capacity to focus on a particular exercise. Mine personnel commonly have other responsibilities, making it difficult for them to dedicate the necessary time. Outsourcing may be particularly relevant for in-depth studies for which resource requirements can be quite substantial.

Regardless of who does the study, it is vital to draw on internal expertise and knowledge. No outsider can know a facility or operation as well as those directly involved in it. At the same time, the intimate knowledge of mine personnel can be a disadvantage. Familiarity can breed a level of comfort and a tendency to sometimes miss the 'obvious'.

If outside consultants are appointed, sufficient internal resources must be committed to provide the study information needed. A common cause of delays and additional cost in risk assessment studies is the time company personnel take to respond to information requests and shortcomings in the information provided. Good communication between the mining organisation and those carrying out the study is essential.

Companies must carefully check the credentials of any parties considered for undertaking studies. It is likely that there will be a range of expertise on offer. High quality risk studies do not come cheaply and cutting corners can lead to future problems, delays and costs as well as greatly diminished value from the exercise.

The question of the appropriateness of using external resources for conducting risk assessment studies should not be confused with the issue of ERM overall. The management of environmental risk must be clearly owned and implemented by company management and personnel.

2.5 ASSESSMENT

Once recognised and analysed, there are a range of possible responses to risk. These can include: accepting the risk; eliminating the hazard or avoiding the risk; reducing the consequences; reducing the likelihood; and risk transfer. A framework of objectives or criteria can provide a rational and consistent basis for evaluating the responses.

When risk analysis aims only to compare cases and identify the least risk option, the analysis may be straightforward and other criteria may not be needed. However, the picture may still be complicated by different risk profiles. Some of the cases being compared might have types of risk that are entirely absent in others. They may have different highs and lows in the types of risk or the risk might impact on different communities or areas. When an analysis aims to rank and identify the highest risk contributors, the need for criteria might similarly be limited. However, risk benefit and cost-effectiveness considerations may become *de facto* criteria. For most other analyses, defined objectives and/or criteria are important.

While the criteria are used largely towards the end of the analysis, the identification, selection or development of relevant criteria should be undertaken early—perhaps with some later refinement. In this way, the criteria can be taken into account throughout the analysis. This will help determine when a hazard can be eliminated from further consideration on the grounds of low consequence or low likelihood; hence outputs can be developed in a form appropriate for assessment against the particular criteria.

While criteria are thus important, it is equally important that the risk analysis and risk management processes do not become exercises in passing 'tests' rather than achieving real improvements in safety and environment protection.

2.5.1 Criteria Identification

The fundamental notion underlying the adoption of risk criteria is that *as all risk cannot be eliminated, some level of risk must be regarded as acceptable or tolerable.* The acceptability or tolerability of a risk varies with the benefits that flow from the risk-generating activity and the distribution of those benefits and risk costs.

At some point, the benefits are considered to outweigh the 'disbenefits' of risk exposure (both the psychological, social and economic costs of the awareness of such risk exposure and the cost when some of the adverse outcomes are realised). Similarly, the benefits of risk reduction or changing the risk profile or incidence might be considered to be outweighed by the cost of the extra safeguards or changes to the activity. At the other extremity, at some level of (severe) consequence the risk may be considered to be unacceptable no matter how low the frequency.

Once the principle of acceptable or tolerable risk levels has been adopted it is clear the objective of risk management is not simply risk minimisation. It is nonetheless important that the principle of 'avoiding avoidable risk' should be followed—where risk can be eliminated or minimised without compromising the technical or economic feasibility or viability of a project, it should be. This concept is sometimes described as ALARP (as low as reasonably practicable) or ALARA (as low as reasonably achievable).

For risk to the biophysical environment, the concept of ecological sustainability and the precautionary principle should be considered in setting criteria and objectives. The significance and relevance of ecologically sustainable development (ESD) and the precautionary principle are discussed in a wider context in the *Environmental Monitoring and Performance* booklet.

In an ideal world, all risk criteria would be based on clear notions of acceptability/tolerability levels and a clear understanding of the consequences of initiating events. In the real world, a full understanding of the potential final impacts of initiating events is often not possible as we don't have sufficient knowledge of the workings of systems. Establishing an acceptability level is difficult with this degree of uncertainty and with the further difficulties of valuing environmental attributes. Consequently, surrogate or intermediate criteria are common (e.g. the likelihood of reaching or exceeding a given concentration in the water or the impacts on individual species), as is conservatism in the levels selected.

The appropriate criteria and objectives will depend on the purpose of the analysis. Criteria may be specified by regulatory requirements, company policy, national or international standards or by particular political or community imperatives. Alternatively, they may be driven by case-specific research or considerations.

Criteria may be available 'off the shelf' or they may need to be adapted, refined or developed from scratch. There are a variety of Australian and overseas documents from regulatory authorities and other bodies provide criteria. However, potentially relevant documents could change with changes in regulations and the nature of the operations and hazards involved. The documents are also subject to revision and new material continues to be developed and released. No attempt has therefore been made here to provide a listing of relevant documents. Some examples have been included to aid the process of identifying appropriate criteria.

Perhaps the best example, in an Australian context, of a broad and fairly comprehensive set of regulatory risk criteria is that in the NSW Department of Urban Affairs and Planning's Hazardous Industry Planning Advisory Paper No. 4 *Risk Criteria for Land Use Safety Planning*. The paper presents well developed criteria for human fatality and injury, property damage and for risk to the biophysical environment.

The DUAP biophysical environment criteria illustrate an important point (see biophysical environment definitions in the box below). Criteria commonly contain qualitative components which require judgments and thus interpretation when applied to an analysis. Even fully numerical criteria (such as a human fatality risk of 1×10^{-6} per year) can have judgmental components in the underlying analysis. Therefore an expression of compliance with a criterion would often need to include some explanation of how the criterion was being applied.

Example Criteria for Risk to the Biophysical Environment

- Industrial developments should not be close to sensitive natural environmental areas if the effects of the more likely accidental emissions may threaten the long-term viability of the ecosystem or any species within it.
- Industrial developments should not be sited close to sensitive natural environmental areas if the likelihood of impacts that may threaten the long-term viability of the ecosystem or any species within it is not substantially lower than the background level of threat to the ecosystem.

Source: NSW DUAP HIPAP No.4 *Risk Criteria for Land Use Safety Planning.*

Some of the other States have similar documents setting out risk criteria for new and existing developments. The main focus of these documents is on industrial development and hazardous materials. They tend to focus more on risk from acute events such as fires, explosions and accidental releases than on health or other risks from continuous emissions or intended releases. They also focus more on risk to people than risk to the biophysical environment. Even so, the criteria can provide useful parameters for risks in mining operations. They can help assess risks to people from sources other than hazardous materials; help assess, to some extent, risks from continuous emissions; and help in assessing risks to the biophysical environment.

In these latter cases, however, it is likely that other criteria such as various air, water and soil concentration standards, and health risk criteria, will also need to be drawn on. In many instances intermediate rather than end-state criteria will need to be used (e.g. the likelihood of exceeding 10% of a water quality criterion value).

Examples of documents that might prove useful are: ANZECC and NH&MRC's *Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites*; ANZECC *Australian Water Quality Guidelines for Fresh and Marine Waters*; Victorian State Environment Protection Authority *Policy Schedule C. C-1 Class 2 Indicators and Design Ground Level Concentrations*; USEPA, FEMA, US Department of Transportation *Technical Guidelines for Hazard Analysis: Emergency Planning for Extremely Hazardous Substances*; WHO—IARC *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*; USEPA *Guidelines for Carcinogen Risk Assessment*; Environment Australia, *National Framework for Ecological Risk Assessment of Contaminated Sites*, Draft 1997. There are also numerous topic-specific sources, such as human, plant or animal toxicity databases, which could be accessed.

An alternative to comparing options and assessing risk against criteria is assessment against some form of qualitative test or objective. For example, demonstrating due diligence may be required for performance-based regulatory, corporate or financial purposes. Such demonstration may also be a dominant objective if senior management is personally liable for incidents and their effects.

2.5.2 Assessing Risk Against Criteria

The assessment process at its simplest is comparing risk results with criteria or objectives. In practice, some interpretation is necessary and the conclusions may need to be qualified.

Where risk levels do not meet criteria it may be appropriate to revisit the analysis and refine it, particularly for sensitivity to conservative assumptions.

2.5.3 Developing Recommendations for Risk Management

The other part of the assessment stage of the process is finalising the development of ERM recommendations. As noted earlier, the recommendations should be drawn from each stage of the analysis. At the assessment stage, however, the effects and interactions of all the recommendations need to be considered in the light of the extent of compliance with criteria.

This may lead to identifying further safeguards or changes needed to the existing or intended operation. It may also lead to the conclusion that some of the measures proposed or included in draft recommendations are unnecessary or not cost-effective.

2.6 MANAGEMENT/TREATMENT

'Treatment' is used here to cover action taken to eliminate, minimise, reduce, monitor or ameliorate risk. This is sometimes termed 'management'—the term 'risk treatment' is used to avoid confusion with the concept that 'risk management' is the overall ERM process as described in this booklet. Whichever term is used, treatment/management is the continuing principal process of ERM once the initial risk analysis and assessment processes are completed.

While risk analysis and assessment can be, to some extent, a stand-alone exercise, it is particularly important that the treatment phase of ERM be integrated with overall risk management, environmental management and overall management.

As indicated in Section 2.5, responses to risk can include: accepting the risk; eliminating the hazard or avoiding the risk; reducing the consequences; reducing the likelihood and risk transfer. Monitoring, auditing and emergency planning also form part of risk treatment/management.

2.6.1 Accepting Risk

Once a risk is known, a company, relevant regulatory authority, community or other interested party can decide the risk is acceptable and that no action is needed to reduce or minimise it. Even when risk is accepted, it may however be appropriate to include the relevant hazard in a monitoring program or in emergency planning. Accepting risk is usually tied to recognising the benefits of the risk-generating activity. The setting and use of acceptable risk criteria is one form of risk acceptance.

Risk acceptance is regarded as a management measure when a risk is known, understood and accepted. It is vastly different from proceeding without adequate analysis and in the absence of informed decision-making.

Depending on the operational context and the hazards and risk involved, the acceptability criteria may be imposed externally. Thus accepting the risk may not be within the mining company's discretion. Even with externally imposed criteria there may, in some circumstances, be latitude for interpreting the criteria and possibly negotiating with authorities who may have some discretion.

2.6.2 Risk Reduction/Minimisation

There are three components of risk reduction or minimisation: eliminating the hazard; reducing consequences and reducing likelihood. There can be considerable overlap between measures taken to eliminate hazards or reduce consequence or likelihood can overlap considerably.

Elimination

Hazards can be eliminated by not proceeding with the risk-generating activity or not proceeding with part of it. Alternatively, changing the nature, scale or way in which the activity is carried out may achieve hazard elimination. For example, by changing technology, changing location or not holding particular materials onsite (using substitute materials or minimising storage).

Consequence Reduction/Minimisation

Worst case consequences can be reduced by attention to the magnitude and severity of the event (e.g. smaller dam—multiple ponds, smaller quantities or fewer hazardous materials) or by limiting or ameliorating the impacts (e.g. secondary containment, emergency response, evacuation, clean up/remediation). Monitoring and early detection and control can play an important role in reducing the potential for adverse consequences.

Likelihood Reduction/Minimisation

Systems can be made more reliable by adopting appropriate hardware (e.g. equipment) or 'software' (e.g. personnel training, maintenance, monitoring and planning). Systems can also be protected from external and internal initiating events, for example, protection against earthquake damage and protection by controlling ignition sources.

The likelihood of intermediate and final outcomes can also be influenced by secondary controls and safeguards, monitoring, emergency response and so forth.

2.6.3 Risk Transfer

Risk transfer describes arrangements that shift responsibility for hazard consequences if they occur and/or of the failure to take other risk management measures. It is useful principally when consequences or remedies are largely financial or where the legal liability can be transferred. Risk transfer does not change likelihood or consequences, just who bears the responsibility.

The most common form of risk transfer is insurance. Insurance can include self insurance by holding a reserve. Other forms of risk transfer can include contractual arrangements between parties and indemnification by government or other parties.

For environmental risk, the consequences may neither be readily remedied nor the affected parties compensated. There may also be non-transferable liabilities and penalties for adverse impacts on the business (for example, bad publicity and distraction of management, viz the Union Carbide/Bhopal case and the Exxon Valdez case) and possible personal fines and penalties including imprisonment for staff, management and directors.

2.6.4 Emergency/Contingency Planning

Emergency/contingency planning covering all environmental hazards should be fully integrated into the ERM. Planning needs to be based on rigorous hazard identification and testing of response capability. The hazard analysis study should be drawn on for the development or updating of the site emergency plans. NSW DUAP's *Industry Emergency Planning Guidelines* may provide some useful guidance for this.

Emergency planning should include provisions for incident reporting, including near miss incident reporting, and timely and rigorous incident investigation.

2.6.5 Monitoring

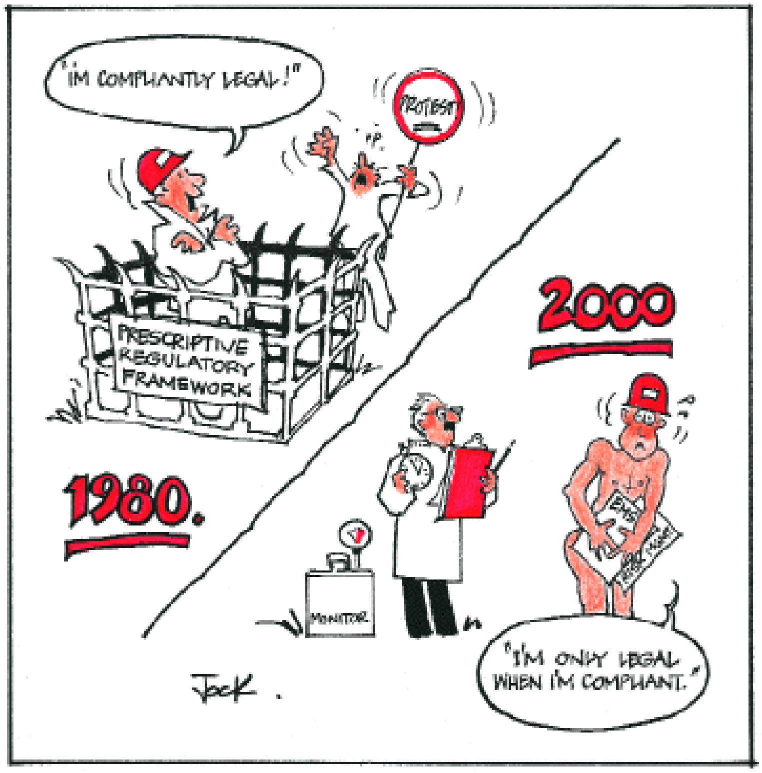
Monitoring environmental performance and the condition and performance of safeguards is particularly important for satisfactory ERM. A sound monitoring program can detect emerging problems or impacts and provide an opportunity to intervene, particularly if impacts are progressive and long term. The environmental risk analysis should be referred to for designing the monitoring program. When logic trees have been used it may be productive to identify indicator events a step or two back from realising an incident or impact so that they may be monitored as early-warning and risk-assessment verification tools.

Monitoring in the wider environmental management context is covered in the *Environmental Monitoring and Performance* booklet in this series.

2.6.6 Auditing

Environmental (hazard) auditing is essential to the integrity of the ERM process. It is not sufficient to rely on a one-off analysis—circumstances change. The auditing needs to address, among others: the implementation of recommendations of the risk analysis and other relevant studies, including previous audits; other key features of the ERM program; and the monitoring systems and performance as they relate to risk-affected aspects. The audit process should also seek to identify any changes that might be significant to the risk profile of the operation, and ensure that such changes will be covered by review and revision of the risk analysis.

Environmental auditing is covered by the *Environmental Auditing* booklet in this series.



2.6.7 Risk Management Program/System

Continuing ERM arrangements should be incorporated into a structured environmental management program or system. This program or system needs to be integrated with safety management, environmental management, risk management and overall management systems.

The environmental risk management program (ERMP) needs to clearly identify roles and responsibilities and how and when risk management actions should be taken. It must particularly address change management and identifying additional hazards and changes to risk levels during transition and under the changed conditions. The change management provisions must recognise relevant change to the external environment and provide for adjustments in managing environmental risk.

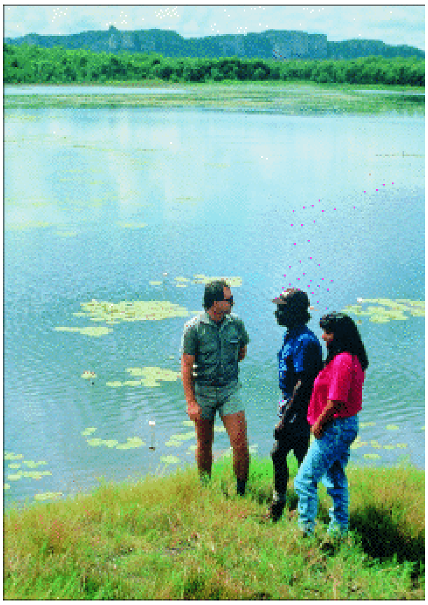


Photo: ERA Ranger Mine

Aboriginal liaison officer and traditional owners discuss water management issues at the Ranger Uranium Mine, NT.

2.7 COMMUNICATION AND CONSULTATION

This can be the most difficult part of the ERM process. It is easy to not consult and to not listen. It is also easy to stimulate concern about risk without providing effective assurance to interested parties that it will be adequately managed. It is much harder to get the consultation and communication process right. However, effort put into the communication process is usually well worth it.

Effective risk communication is, or should be, a two-way process. It is not just about hearing what all interested parties (including the local and broader community, government authorities and special interest groups) have to say about their concerns and accessing their information, perspectives and insights. It is also about providing clear and accessible information on results of risk analysis and the ERMP.

Risk communication needs to be seen as integral to ERM. As shown in Figure 1, it should introduce the process and continue throughout the life of the mining operation. It should not be seen as an adjunct at the end to simply inform the public of the assessed levels of risk and the intended management arrangements.

The process should involve accessing the knowledge of outsiders, understanding their perspectives and providing them with information held by the company on its operations, risk and perspectives. The same two-way process is needed for company personnel. Obviously the personnel of the mining operation have practical experience and expertise that others will not. Effective ERM cannot be achieved unless the board, management and workforce also know about the risks, how they are generated and controlled and the importance that is placed on soundly managing them.

The ERMP also needs appropriate, continuing communication with interested parties outside the organisation. Consideration should be given to structured community participation in monitoring and auditing processes.

How risk is perceived differently is a significant issue in the communication process. The process of risk analysis described above focuses largely on qualitative or quantitative estimates of 'actual' or 'real' risk. However, it is often the case that different stakeholders perceive risk differently. The perceived risk commonly varies widely from the estimated risk, not just for aspects such as severity or likelihood but in more fundamental ways. Appropriate management measures cannot be developed without an understanding of perceived risk. The risk analysis cannot be complete without input on perceived risks.

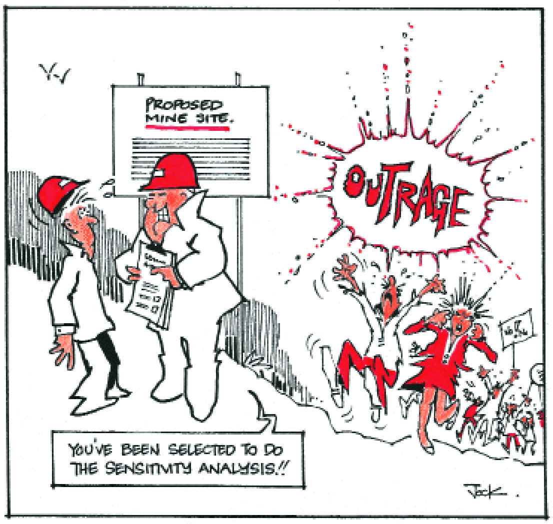
There is an extensive and diverse literature on risk communication and risk perception. Much of it suggests that perceived risk is just as real as 'actual' risk. One prominent suggestion is that risk, defined from a technical perspective, is too narrow and that it should be redefined to include both the technical (actual) risk and the 'outrage' stakeholders feel. 'Outrage' encompasses concepts such as fairness, familiarity, 'voluntariness' control, and trustworthiness of the organisation(s) promoting or controlling the risk generating activity. This is a useful notion to the extent that it can aid the design of risk analysis studies and communication processes so that issues of significance to interested parties are addressed.

Even given the view that perceived risk should be treated with respect and management processes designed with a degree of recognition and acceptance of the risk perception, there is still merit in initiatives aimed at bringing the perceived and estimated risk together. This may require an attempt to bring perceived risks 'down' to the estimated levels. However, it may also mean bringing perceptions 'up' towards the estimated levels, particularly if company personnel responsible for the analysis have not previously been exposed to environmental risk issues.

It is often assumed that company personnel know all about the risks associated with its operations. All too often, however, their perceptions do not mesh with the outcomes of risk analysis. Risk is often underestimated—familiarity can breed complacency and significant risk underestimation. Appropriate training for all relevant personnel is therefore necessary.

The credibility of the risk analysis can significantly influence acceptance of the appropriateness and adequacy of ERM for an operation. Ensuring that the risk analysis is demonstrably rigorous and well executed may not be enough. The use of independent parties to conduct the risk studies and audits can also be significant.

The *Community Consultation and Involvement* booklet explains how to consult the community and encourage its members to contribute to environmental matters. A good summary of the issues covering risk communications and trust are provided by Covello (1999).



3. ERM AND THE MINING CYCLE

As mentioned in section 1, it is appropriate that ERM be applied to all phases of the mining cycle and all parts of mining operations. The subject matter of ERM consequently crosses that of the other booklets in this series. This section is intended to emphasise the interrelationships and give some specific guidance on cross referencing to the other booklets. There is necessarily some repetition of the points raised in earlier sections.

3.1 PLANNING AND CONCEPT DEVELOPMENT

When mining facilities or operations are developed or modified, the importance of building ERM into the planning and concept development cannot be overstated. As stressed in the *Mine Planning for Environment Protection* booklet, considering ERM issues early can steer planning and concept development down paths that avoid significant and costly problems and delays.

Fundamental decisions made in these initial developmental stages could have significant environmental risk implications that may be hard to address later. Basic matters such as the location and layout of mine workings, processing facilities and choices of mining method and technology are examples.

The siting of an underground mine's headworks, for example, could affect a range of issues. For example, the site could determine which catchment could be affected by contaminated water releases or the potential for significantly affecting some plants or animals. Locating mineral processing facilities at the mine, or transporting the ore for processing elsewhere, could change the hazards and risks associated with both these operations. Choosing open cut or underground mining technology exemplifies the differences in the potential and range of environmental risk impacts at the surface. Issues such as mining sequence and optimal mining duration could also markedly influence environmental risk.

'No go' areas are sometimes a difficult issue but must be covered early in mine development. There is a need to accept in principle that *some areas may be too sensitive for mining to be acceptable*, even where the likelihood of adverse consequences is considered very low. It is important in understanding risk management that, just as low consequence events can be tolerated at relatively high frequencies, at some level of consequence even extremely low frequencies may not be sufficient justification. The precautionary principle, the limits to knowledge and the uncertainties involved in ERM are highly relevant to this.

The extent of risk analysis work required at this stage will vary from case to case. A separate preliminary risk review may be appropriate. A hazard identification with the brief of identifying anything that would preclude mining, be too expensive to deal with or produce an unacceptable level of uncertainty might also suffice. Alternatively, it might be appropriate to proceed with detailed work as part of the ERM for the project as a whole. The degree of certainty and commitment to the project at this stage could be significant in determining the level of detail required. In some instances an iterative approach might be appropriate.

3.2 EXPLORATION

The exploration phase should not be overlooked as a source of environmental risk and exploration programs should be subjected to ERM.

Photo: DFAT

Before exploration activities begin, early community liaison should take place.

The exploration process has, for example, the potential to introduce and spread plants and animals and to spread pathogens such as the fungus that causes jarrah dieback. If the exploration process opens up access to an area, the risk impacts associated with the enhanced access should not be ignored. These could be, for example, increased bushfire risk from recreational four wheel drive access and other disturbance and destruction of habitat.

Environmental issues associated with exploration and low impact exploration techniques are discussed in the *Onshore Minerals and Petroleum Exploration* booklet.

3.3 EIA AND APPROVAL PROCESSES

It is increasingly common to have a formal requirement for risk analysis/assessment, including environmental risk analysis/assessment, as part of the requirements for impact assessment for regulatory approvals. The *Environmental Impact Assessment* booklet covers impact assessment in general, and notes the importance of issues such as environmental risk. For ERM, it should be read in conjunction with this booklet.

Important subjects that are sometimes not adequately covered in environmental risk studies in the EIA process include transport and remote processing operations; ESD issues; and 'whole of mining cycle' issues, particularly longer-term, post-mining aspects.

3.4 DEVELOPMENT AND CONSTRUCTION

Some hazards and risks are peculiar to the construction phase during which there may be a high likelihood of events of high consequence occurring. It is not unusual, even when the operational phase issues have been dealt with relatively carefully, for issues associated with the development and construction phases to have been largely ignored. These phases can include major modifications and demolition activities and should be subject to rigorous ERM. The requirement for such analysis and management should be built in to the changed management procedures in the environmental management system and the ERMP.

3.5 OPERATIONS

It is important that ERM is recognised as a continuing activity—not a snapshot assessment process. The *Environmental Management Systems* booklet covers the environmental management systems for mining operations. As discussed in section 2, it is important that ERM is fully integrated with the environmental management systems and with the environmental management program, environmental auditing and environmental monitoring. The changed management provisions of the EMS should in particular incorporate ERM provisions.

3.6 DECOMMISSIONING AND REHABILITATION

The environmental risk associated with the impact of mining operations after the mining phase should be fully considered in ERM. This should be covered at the outset of the process for a new mining development and kept under review through the operational phase. For existing mines, the post-operational phase should be covered by the ERM. The likely costs associated with post-mining risk management should be carefully considered in assessing the viability of the mining operation.

The *Rehabilitation and Revegetation* booklet addresses some of the relevant issues.

3.7 REMEDIATING FORMER MINING SITES

Former mine sites are a special case that may show high levels of environmental risk. Typically, such sites may be contaminated and unavailable for beneficial use without remediation. They may be susceptible to potential adverse impacts from containment structure failure, leachate/contamination of surface or ground water, erosion/siltation, weed invasion and so forth.

Some sites are abandoned and the organisations that undertook the mining defunct. The threat to the environment may, however, still be very real and ERM may help devise adequate and cost-effective strategies to address the hazards. For contaminated land, for example, risk analysis can provide the basis for matching remediation to an acceptable level of risk exposure for a particular future use.

4. RISK MANAGEMENT AND THE FUTURE

Given environmental awareness and regulation trends and growing global environment pressures, it is highly likely that requirements for a high standard of environmental management will increase. Increasing awareness of our knowledge limits (particularly about environmental impacts and the uncertainties in complex systems) is likely to further increase risk-based decision-making. It is highly likely, therefore, that ERM will play a bigger role in the environmental management of mining in the future than it does today.

Additional performance-based regulatory requirements are likely to foster this trend. At the same time, there is the continuing move in Australia and other OECD nations to make directors, managers and workers personally liable for environmental incidents. This should result in an increased use of risk analysis/assessment to demonstrate due diligence as a defence should incidents or undesirable outcomes occur. The global trend for society to be increasingly litigious will also tend to reinforce the need for demonstrably sound ERM.

The current trend of introducing risk and performance-based approaches for regulatory matters that overlap with ERM, including OH & S matters, dangerous goods control and landuse control could also be significant.

On the technical side, greater experience with using ERM in mining will promote further development and refinement of tools, especially those for coping with the consequences of releasing toxic or polluting substances to the aquatic environment. Risk criteria, including those for the biophysical environment, are likely to be progressively developed, refined and standardised.

There may also be moves to codify risk assessment protocols and possibly standardise consequence models and some datasets (e.g. equipment failure frequency and toxicity data). The rapid ranking and matrix type approaches are likely to be further refined and used alongside the more detailed case-specific risk analysis.

In line with the national trend for government to devolve the responsibility for ensuring sound environmental management to the operating organisation, it is likely that there may be moves towards accreditation of consultants and others assessing risk and auditing environmental hazards.

Longer term perspectives and issues such as greenhouse gas issues, climate change, ESD and intergenerational equity are all likely to become major factors in ERM. Pressure for quality risk communication might also be expected to grow.

Overall it would seem that ERM in mining will only grow in importance and that there will be significant benefits in heading down this path sooner rather than later.

CASE STUDY 1

CONTAMINATED WATER RETENTION AND TREATMENT SYSTEM GUIDELINES

In July 1994 the Hazardous Materials Policy Co-ordinating Committee of the New South Wales Government published *Best Practice Guidelines for Contaminated Water Retention and Treatment Systems*. While initially developed for industrial and chemical and fuel storage facilities, its approach and methodology is essentially applicable to any activity or operation which can discharge contaminated water from site.

The guidelines apply to both new (proposed) and existing facilities. They aim to help develop contaminated water management systems which are sufficient to meet the site's hazard potential without being excessive.

Factors Relevant to Contaminated Water Systems

Many factors influence the need for and design of contaminated water systems, including:

- the nature and quantities of materials handled and the type of storage and packaging—physical state, toxicity, solubility/miscibility etc.;
- the sources of potentially contaminated water—rainfall on site that becomes contaminated by materials spilled or deposited as dusts etc. on unroofed areas or through inundation entering buildings/roofed areas and possibly causing loss of containment; water used to extinguish a fire or to protect or cool other structures (tanks etc.) to prevent incident propagation and to clean up afterwards; and leaks or discharges of process or waste water including stored waste water awaiting treatment. The direct discharge of released liquid hazardous materials through site drainage is also a relevant source of contaminant discharges to the receiving waters.
- the volumes of potentially contaminated water requiring handling in a given time period—intensity, frequency and duration of rain; duration and likely frequency of fire events and the rate of water will be applied; volumes of process and waste waters handled and stored etc.
- the extent to which potentially contaminated water flows are separated from flows from clean areas;
- the extent to which handling and storage of hazardous materials takes place in the open or in roofed areas;
- the extent and scale of credible release scenarios for the contaminants;
- the nature and scale of the potential contamination—type of material and loading;
- the options available for treatment or disposal of retained waters e.g. is discharge to sewer available, or use as process water?;
- the time taken to test and dispose of water which is clean and the time taken to test, treat and dispose of water which is contaminated;
- the available retention capacity in tank farm bunds, building and loading area bunds, drainage sumps, stormwater retention ponds, and site bunding;
- physical site constraints on the provision of retention capacity;
- the hydraulic and biological characteristics of the receiving waters;
- the relative costs and benefits of different approaches; and
- the risk acceptability criteria to be applied.

Methodology

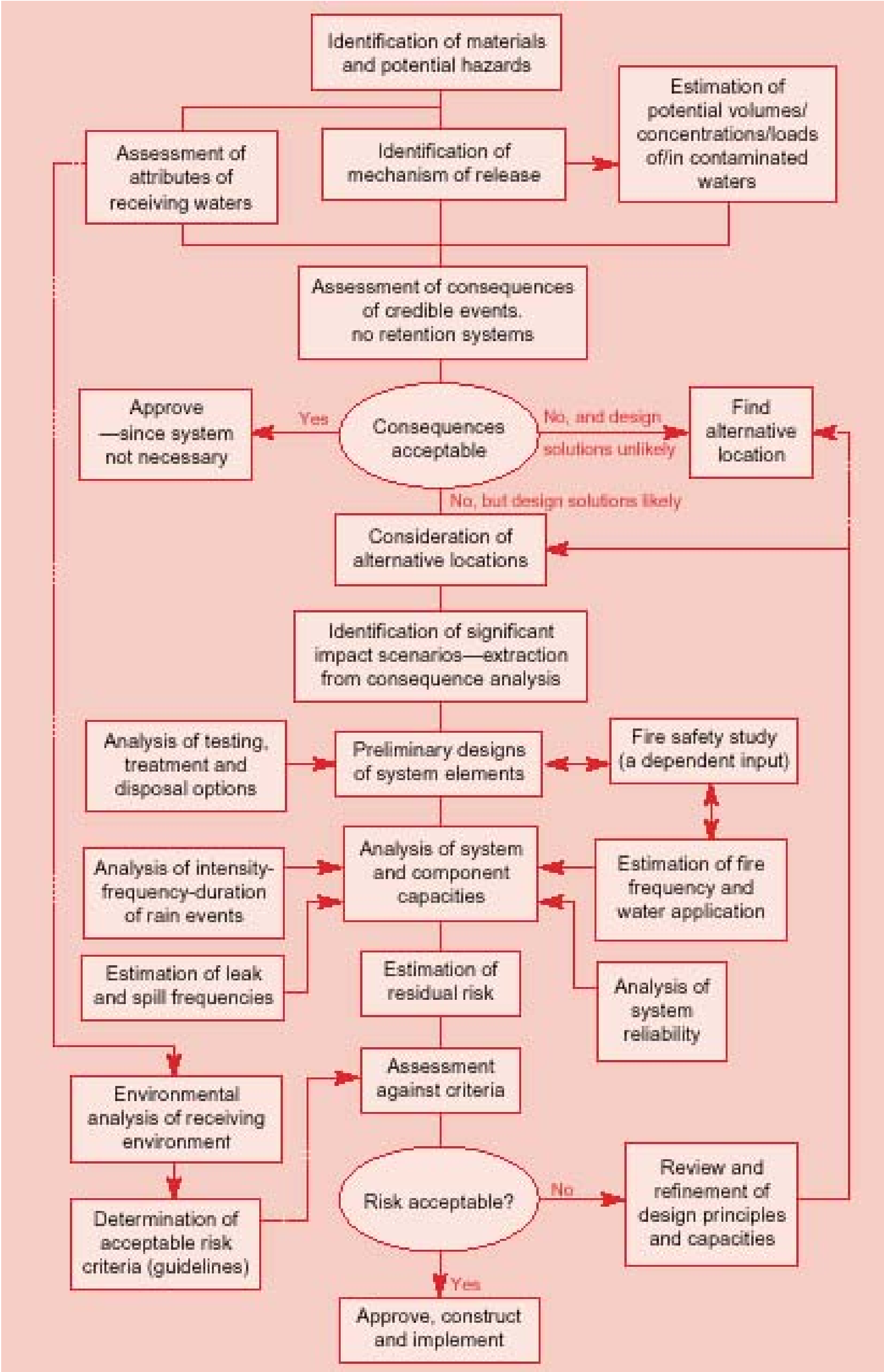
The methodology is based on hazard analysis and quantified risk assessment. It involves:

- identifying all materials stored or processed on site with potential to harm the environment in their current state or after combustion or reaction with other materials held, and identifying scenarios which could result in significant discharges of contaminated water;
- analyse the impacts of such discharges on receiving waters and the environment;
- analyse the likelihood of such discharges (where they may be significant) and of the likelihood of circumstances leading to particular outcomes;
- estimate risk through the combination of consequence and likelihood information; and
- assess the risk against risk acceptability criteria.

A contaminated water design methodology is set out schematically in the figure opposite. While the diagram indicates a linear process, a degree of iteration is common.

The process depicted is the preferred approach for a new plant. Contaminated water issues and the system design are built into the plant's conceptual and detailed design from the outset. The order and nature of the elements would need adjustment for the existing system assessment case.

An important principle in applying the guidelines is that the system should meet the needs of the case. Erring on the conservative is appropriate (i.e. using a value which will tend to show outcomes as worse than they really would be, rather than values which show the results to be better) in assumptions and selecting design features. However, it must also be recognised that some facilities only need simple systems or no special containment if consequences of contaminated water discharges are not significant or risks are low.


Identification of materials and potential hazards
Assessment of attributes of receiving waters
Identification of mechanism of release
Estimation of potential volumes/ concentrations/loads of/in contaminated waters
Assessment of consequences of credible events. no retention systems
Approve —since system not necessary
Yes
Consequences acceptable
No, and design solutions unlikely
Find alternative location
No, but design solutions likely
Consideration of alternative locations
Identification of significant impact scenarios—extraction from consequence analysis
Analysis of testing, treatment and disposal options
Preliminary designs of system elements
Fire safety study (a dependent input)
Analysis of intensity-frequency-duration of rain events
Analysis of system and component capacities
Estimation of fire frequency and water application
Estimation of leak and spill frequencies
Estimation of residual risk
Analysis of system reliability
Environmental analysis of receiving environment
Assessment against criteria
Determination of acceptable risk criteria (guidelines)
Risk acceptable?
No
Review and refinement of design principles and capacities
Yes
Approve, construct and implement

CASE STUDY 2

DEVELOPING A COMPREHENSIVE DIEBACK MANAGEMENT SYSTEM

Establish the context

Alcoa World Alumina—Australia operates open cut bauxite mines in the Darling Plateau, 90—130 km south of Perth. Currently, the operations clear and rehabilitate 550 ha per year. The natural vegetation community of this region is tall open forest dominated by jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*). This community is botanically diverse but many of the plant species are susceptible to a disease called 'dieback'. This disease is caused by the introduced root pathogen *Phytophthora cinnamomi*. This disease can kill jarrah trees, decrease botanical diversity and change the species composition of the community. Forest infested with *P. cinnamomi* is widespread but large areas of uninfested forest exist.

Photo: Alcoa World Alumina—Australia
Healthy jarrah forest.

Forest management authorities have established various regulations to minimise the spread of dieback by forest users. Essentially, these restrict access to some areas and provide conditional access to the rest. The pathogen is easily spread in water and moist soil so conditional access usually involves seasonal constraints on operations. These constraints allow most operations to occur under dry soil conditions in summer months, but prevent vehicular activity in wet soil conditions, mainly late autumn to early spring. However, the alumina refineries require bauxite ore all year because refining is a continuous operation.

In 1990, Alcoa's Huntly mine was scheduled to mine a new locality with a high proportion of uninfested forest. Alcoa has a major environmental objective to minimise the spread of dieback during its mining operations, so the challenge was: to develop a mining and environmental management system that allowed year-round access to the ore reserves, minimised the spread of dieback, and was economical. Dieback management has been an important environmental component of Alcoa's mining for twenty years so all operators had knowledge of the disease and existing control measures. Alcoa has also supported joint research projects on dieback with government agencies and universities over that time. Consequently, the organisation was well placed to assess and manage the risks associated with mining in this environmentally sensitive area of forest.

Identifying the hazards

Alcoa established a multi-disciplinary team of mine planners, field supervisors, environmental officers, production managers and a research scientist to develop appropriate mining procedures to minimise the risk of spreading dieback. The generic hazards associated with mining in this mosaic of infested and uninfested forest were identified as:

- transporting infested soil into uninfested forest.
- mixing infested and uninfested soil.
- generating surface runoff from an infested area that then flows into uninfested forest or soil stockpile.

The team determined the risks would need to be analysed, because they could affect most stages of mining.

Photo: Alcoa World Alumina—Australia
Severely affected dieback forest.

Analysing and assessing the risks

The team systematically reviewed every stage of mining to assess:

- the likelihood of spreading the pathogen;
- the effectiveness of existing control procedures;
- the cost of the control procedures; and
- whether the procedures were practicable.

The consequences of spreading the pathogen were not discussed in detail because it was realised that the level of consequence was related to several factors. These included the area of uninfested forest adjacent to the minepit or the susceptibility of particular forest types to the pathogen. These factors vary from pit to pit, requiring a review of the consequences on a case by case basis.

The risk of spreading the pathogen was assessed by examining:

- the likely density of pathogen spores in the material being disturbed during mining;
- the likelihood of vehicles inadvertently transporting infested soil into uninfested areas;
- the likelihood of mining causing water to drain from an infested site into uninfested forest or soil stockpiles; and
- the likely amount of soil or volume of water that could be transported into the uninfested area.

Risk analysis was based on the scientific understanding of the pathogen and operational knowledge of the mining process. Some of the critical information about the pathogen came from research funded by Alcoa and from the company's R&D program on dieback. In the team, the scientist contributed data on the likely presence of the pathogen, while the field operators had the practical knowledge on transporting soil and altering drainage patterns. Risks at each stage of mining were ranked as high, medium and low.

Many of the chosen control procedures involved changing mine schedules to exploit the seasons when the soil is dry and the risk of inadvertently spreading soil and water is very low. Mine planners helped determined if changes to schedules were achievable. In some cases, no 'off the shelf' control procedures were deemed suitable and new procedures had to be developed. Again, the scientific and operational knowledge of the team members created new procedures that effectively minimised the spread of dieback but were also practical in the field.

Treating the risk

All team members reviewed existing control procedures, refining their effectiveness and assessing their cost. Expensive procedures were only considered for high and medium ranked risks. Where no existing procedure was assessed as effective and economic, new procedures were proposed. Each proposal was evaluated to determine if it was effective, economic and practicable.

At the end of the process, the team documented procedures for dieback control at Huntly mine and Mining Department management fully supported this document. It also had full support of the field supervisors and mine planners who expressed strong 'ownership' of it. Government authorities also endorsed this Comprehensive Dieback Management System (as it became known) and constraints on the season of mining were removed for many mining stages.

Monitoring and reviewing

A detailed monitoring program was also put in place to assess the effectiveness of the dieback management procedures. In 1996, forest classified as uninfested prior to mining was re-mapped for the presence of dieback. Only 6.11 ha of recently infested forest was found adjacent to 1253 ha of land which had been cleared for mining. It was assumed this spread was attributable to mining. It was assumed this spread was attribable to mining. This is a very low level of spread and corresponds to 0.005 ha of new infection for every hectare cleared for mining.

Major audits of the dieback management procedures occurred in 1994 and 1997. These audits assessed the mine's compliance with the documented procedures and the level of knowledge and understanding of the procedures. Opportunities to improve procedures were identified as part of these audits.

The procedures continue to be revised. The need for revision is based on four factors: improved information about the risk of spreading the pathogen, practical problems associated with procedures, accurate costs of their implementation and introducing new stages to the mining process.

Photo: Alcoa World Alumina—Australiatd>

Vehicle washdown area. All soil and mud are removed from vehicles before they enter the Huntly mine.

CASE STUDY 3

COMPUTER MODELLING OF OIL SPILLS

Apache Energy Limited is a partner in the operation of seven oil and gas platforms on the North West Shelf off the coast of Western Australia. The North West Shelf is an extension of the Australian continental shelf and is dotted with hundreds of islands, reefs and sandy cays. The region has a rich biological diversity including whales, sharks and turtles as well as numerous species of fish, plankton, corals, seagrasses and mangroves.

Apache Energy recognises that oil spillage during exploration and production activities is always possible. It also recognises that should a spill occur, its potential impact on the local and regional marine environment could be significant and that appropriate emergency response is a major factor in limiting the impact.

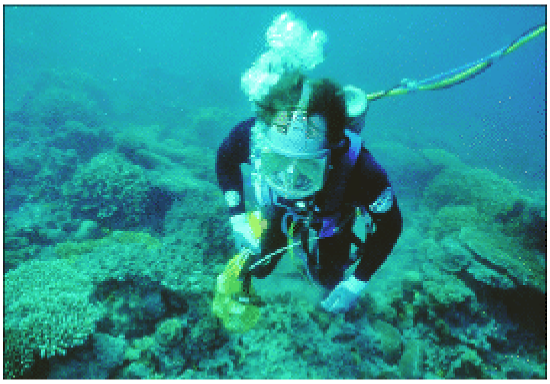


Photo: Apache Energy Limited

Monitoring corals to determine their distribution and community characteristics. This provides baseline information on corals in case of a major oil spill.

Apache was instrumental in developing a computer model to be used as a tool to predict the chances of oil from a particular spill coming into contact with the surrounding environment. The model (GCOM3D) also identifies the areas which may be contacted by oil and estimates the magnitude of the impact in terms of quantities of oil, extent of affected area and the time that has elapsed since release of the oil.

Apache uses the model in risk studies for particular drilling operations. Briefly, the method involves:

- Identifying and describing the types and sizes of spills (of oil and other materials) which might occur and a representative set of spill scenarios and sizes. It also reviews oil spill data for the North West Shelf area, for Western Australia and Australia as a whole, and Apache has drawn on an international oil spills database to establish relevant spill frequency data.
- Developing acceptance criteria based on a combination of likelihood of spill contact with the area and the period required for recovery from oil impacts.
- Surveying and describing the natural environment which could potentially be affected. This includes the physical landform, the type of material comprising the shoreline and the sea floor, water depth, types of land use, and plant and animal species present in the sea and land areas potentially affected.
- Randomly selecting a large number of occurrence times for each representative spill event to ensure representative coverage of wind, tide and sea conditions.
- Modelling the transport and weathering of the spilled material under the influence of the tide, wind and currents. This step uses the newly developed

model which combines two complementary modelling systems OILMAP (which models the movement and weathering of the oil) and OILTRAK (a three dimensional ocean model which helps predict ocean currents, taking into account changes in water depths and current flows). The model produces plots showing the probability of oil arriving at particular reef or shore locations, the maximum volumes of oil reaching the various locations and the minimum time before arrival.

- Analyse the impacts of the types and quantities of oil on potentially affected landforms, ecosystems and species; identifying the most vulnerable locations and determine the sensitivity of particular locations and recovery times.

Photo: Apache Energy Limited

Groundtruthing the shallow water habitats around the islands—'this was hard work!'

- Combining the probability of contact results with recovery time information to produce risk results in the form of the acceptance criteria.
- Compare the risk results with acceptance criteria.
- Develop (and subsequently implement) risk reduction measures, including emergency response planning incorporating the real time modelling capability to help identify the optimum allocation of spill containment and clean up resources. Identified risk reduction measures identified have included:
    - restricting particular operations to times of the year when prevailing winds are favourable;
    - developing technical and operational precautions such as minimising the number of refuelling operations and using equipment which reduces the likelihood of spills (e.g. dry break couplings);
    - providing appropriate spill containment structures and spill containment and clean up equipment;
    - monitoring of critical operating conditions (e.g. abnormal pressure parameters in the drilling well); and
    - training all crew.

The new model is now being used widely in the Western Australian oil and gas industry and is being adopted by the Australian Maritime Safety Association (AMSA) as a national system. The oil spill trajectory modelling software OILMAP in combination with high quality 3 dimensional hydrodynamic modelling (GCOM3D) and real time data oceanographic and meteorological information from the Bureau, has been adopted as the national maritime pollution modelling system, as well as supporting the search and rescue planning functions of AMSA.

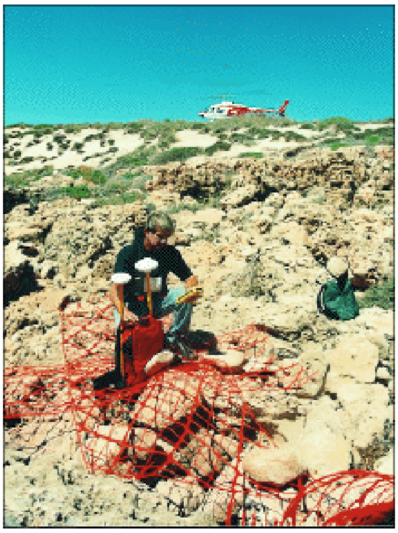
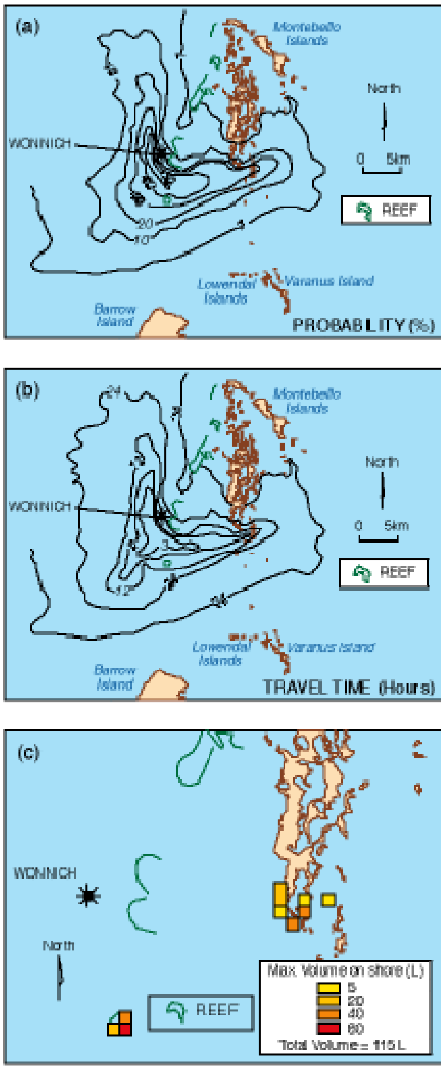


Photo: Apache Energy Limited

Aerial photographs were rectified prior to groundtruthing the habitats of the region. Scientists from CSIRO used differential GPS to confirm the locations and distribution of the various types of habitats.



Contour diagram (a): *The probability of oil arriving at particular reef or shore locations.*
Contour diagram (b): *The minimum time before oil reaches the locations is also estimated.*
Contour diagram (c): *The maximum volumes of oil which may reach the various locations.*

CASE STUDY 4

RISK STUDY FOR DEVELOPMENT APPROVAL

Background

The Tritton Copper Project is a joint venture of Nord Australex Nominees Pty Ltd and Straits Mining Pty Ltd. It involves a relatively small underground mine, facilities for producing a copper concentrate and transporting concentrate to Port Kembla on the New South Wales south coast from the mine near Nyngan in central NSW.

The project underwent development approval in 1998—9. Regulatory authorities required a risk study (referred to as a preliminary hazard analysis of PHA) as part of the EIS. The company commissioned specialist risk consultants to carry out a PHA, as briefly described below, to help regulatory authorities assess any environmental risks associated with the project.

Familiarisation and Hazard Identification

The EIS and other studies were the basis of familiarisation work. As the design had been refined, partly as a result of study findings, clarifying detail with company personnel and their consultants was also essential. This important step in the analysis soon made it clear that certain design features could have a significant impact on possible risk levels.

The project description derived from this process was reviewed and verified by staff, then used for comprehensive hazard identification. Issues considered in the hazard identification included:

- soil erosion and siltation;
- acid drainage;
- soil contamination;
- surface water and groundwater contamination;
- explosion, including vibration impacts on surface structures and landforms;
- subsidence impacts;
- dust deposition;
- unintended chemical reactions;
- toxic combustion products and contaminated fire fighting water;
- impact on wildlife; loss of containment of tailings;
- spillage, fire and explosion hazards when transporting processing chemicals to the site and ore concentrate from the site;
- introduction/establishment of weed species or plant or animal disease;
- natural hazards such as flooding, bushfires, earthquake and strong winds; and
- interruption of services e.g. electricity.

The hazard identification process also included a review of the properties of the mullock, ore, concentrate and tailings as well as the process chemicals and explosives.

Risk Analysis

The Tritton Project has several features which inherently reduce the hazard potential, including:

- the relatively small scale of the operation;
- its location in a sparsely populated area;

- the relatively large size of the mining lease and the comparatively small mine workings within it;
- the absence of other development in the vicinity;
- low rainfall and the absence of perennial streams or permanent water bodies;
- the poor quality of the groundwater and the fact that it is not in current or likely future use; and
- the small volumes and low toxicity of the processing reagents.

Photo: Nord Australex Nominees Pty Ltd

Nyngan, NSW (1996). Exploratory drilling can assist in identifying environmental risks.

These features and the nature of identified hazards meant most issues could be adequately dealt with using largely qualitative analysis. It was appropriate to carry out the hazard identification and consequences and likelihood analysis concurrently. The analysis nonetheless involved some quantitative considerations, such as:

- calculating concentrations of materials in the tailings waters for various spill scenarios; and
- analysing the rainfall conditions which could lead to loss of containment from the tailings storage facility (TSF) and the likelihood of such conditions arising.

Given the proposed mine's isolation from people and from vulnerable environmental systems, potential chemical reaction, fire and explosion events on site had no significant consequences off site nor any significant long term potential impact on the environment within the site.

Spillages, runoff or leachate from ore stockpiles or mullock, most deposited crushed ore dust and any contaminated fire fighting water, if not contained beforehand, would all flow to the TSF and be confined on site unless there were releases from the TSF.

As contaminated materials from other sources might flow to the TSF, the tailings, tailings waters and any leachate or drainage from the tailings might have environmental impacts if not contained. The integrity of the TSF was thus a key determinant of risk.

The proposed safeguards, including monitoring and maintenance systems, were sufficient to ensure that undetected discharges of substantial volumes, either from underflow or through the TSF containment wall, were unlikely. The combined characteristics of the waters which could be released, and the likelihood that the volumes of water in the more likely releases would evaporate or be absorbed well before reaching the nearest receiving waters (tens of kilometres distant), also reduced the potential risk from such events.

Given the TSF design capacity at the various mine stages, the reuse of supernatant waters as process waters and the relatively small TSF catchment, it was clear tha—provided the progressive TSF development went as planned—overflow events could only result from extreme rainfall events or extended wet periods. Consequently, dilution factors both within the TSF and downstream would ensure that overflow events would not have significant consequences unless they also lead to containment structure failure.

Only overflow leading to catastrophic TSF containment wall failure presented a potentially significant problem. Such a failure, in high rainfall conditions was identified as having some potential to carry tailings solids with it and, by spreading them downstream, create the potential for future oxidation of sulphides and acid generation. Whilst clean up might prove effective, it was clearly preferable to ensure that the likelihood such an event was sufficiently low.

The Tailings Storage Facility was designed with available capacity to hold the inflow from a 72 hour storm event in a defined recurrence period. Analysis showed this did not of itself provide a basis for determining the frequency of overflow events, as it did not consider whether the TSF might already hold substantial volumes of water from earlier rainfall or any delay in raising the embankment. A key study recommendation was reviewing the design basis but, regardless of the that review outcome, the containment wall should at all times have a spillway of sufficient capacity to handle maximum credible inflows, thus effectively eliminating the possibility of overflow induced wall failure.

Unlike on site activities, transportation operations brought materials closer to people and to potentially environmentally sensitive areas. Here, the contribution to risk from moving process chemicals, fuels and explosives to the site was assessed as making no significant contribution to risk (in terms of background levels of traffic in these materials due to small volumes and numbers of movements involved). Transporting the copper concentrate was more significant, but its properties limited hazard potential to events involving directly depositing a load into a sensitive water body and even then only if the load were not recovered and was left in situ for an extended period.

The planned route did not pass or cross many sensitive water bodies and it was considered that in almost all circumstances it was possible to recover most of any spilled load, especially given strong financial incentive to recover the material. Even without detailed quantification, it was clear that any risk from this source would conform to the relevant criteria. Nonetheless, procedures were recommended to ensure prompt recovery of the material.

Another key recommendation was that all the proposed safeguards, including monitoring, which were keys to study assumptions, should be formalised in an (environmental) Safety Management System (SMS). This would be integrated with the overall environmental management system for the site and its operations. It was recommended that the SMS incorporate emergency response arrangements, including transport spillage clean up.

Findings and Conclusions

The risk study found that were that provided that it was carried out essentially as described and the recommendations were implemented (especially those for continuing environmental safety management):

- there would be no significant fatality or injury risk to people off-site from the development or operation of the mine or in its rehabilitated state.
- the only credible source of risk to the biophysical environment was a failure of the tailings storage facility embankment/dam when the available capacity above the deposited tailings was full of water and under conditions of continued heavy rainfall. Providing spillways capable of carrying the flows from the peak rainfall intensity for each of the five stages of the TSF should ensure that the risk of coinciding embankment failure and heavy rainfall was reduced so low that it was not effectively credible.
- there would be no significant risk to people or the biophysical environment from transporting process chemicals, fuel or explosives to the site.
- there would be no significant risk to the biophysical environment from transporting the copper concentrate, especially with appropriate emergency response arrangements.

Photo: Nord Australex Nominees Pty Ltd

Nyngan, NSW (1996). Site meeting involving Dept Mineral Resources, Aboriginal Councils, Environmental agencies etc.